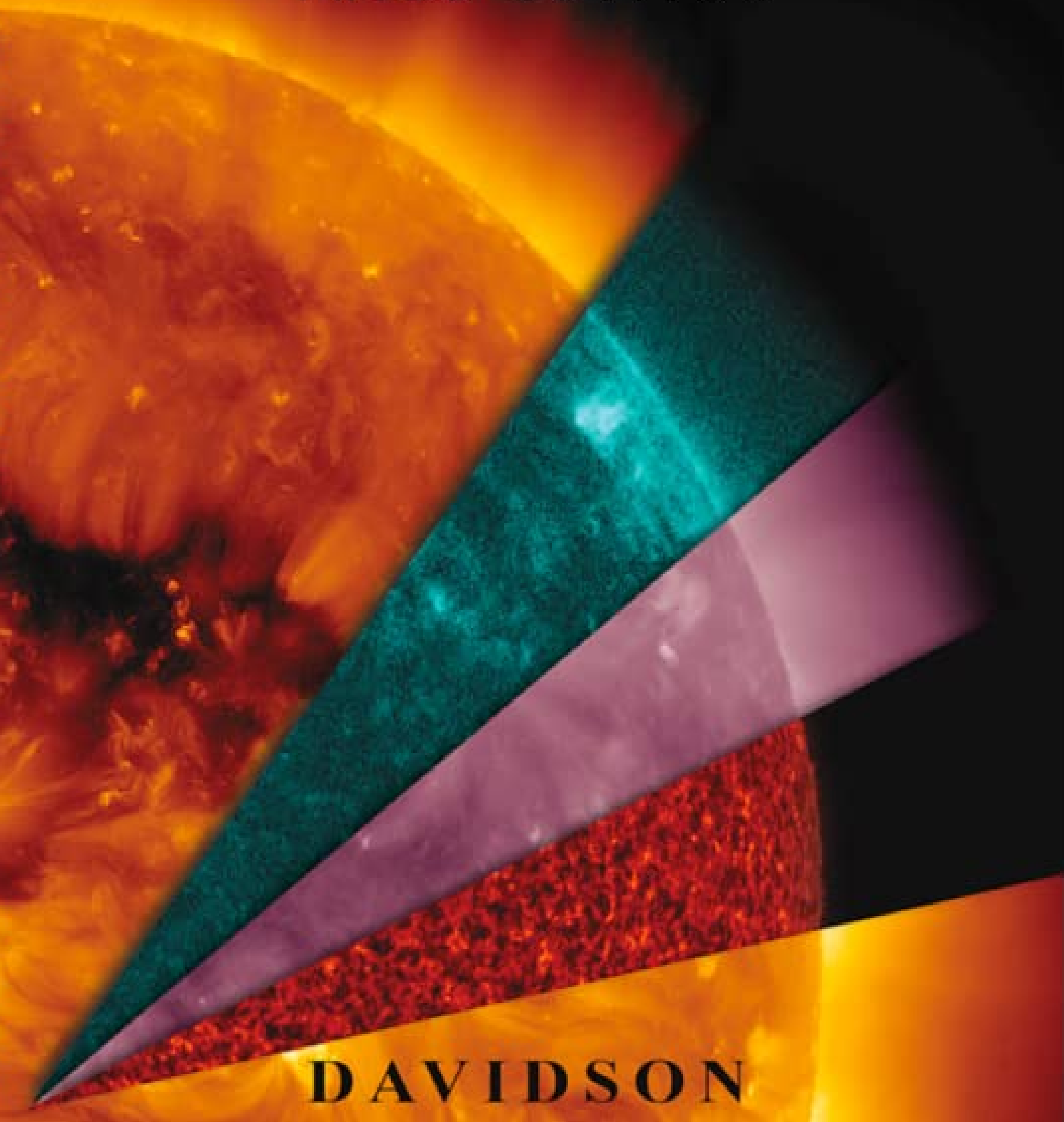
Weatherman's Guide to the Sun

THIRD EDITION



DAVIDSON

Weatherman's Guide to the Sun
3rd Edition

Ben Davidson

Space Weather News

2020

Colorado Springs, Colorado, USA

Eyes Open, No Fear

Contents

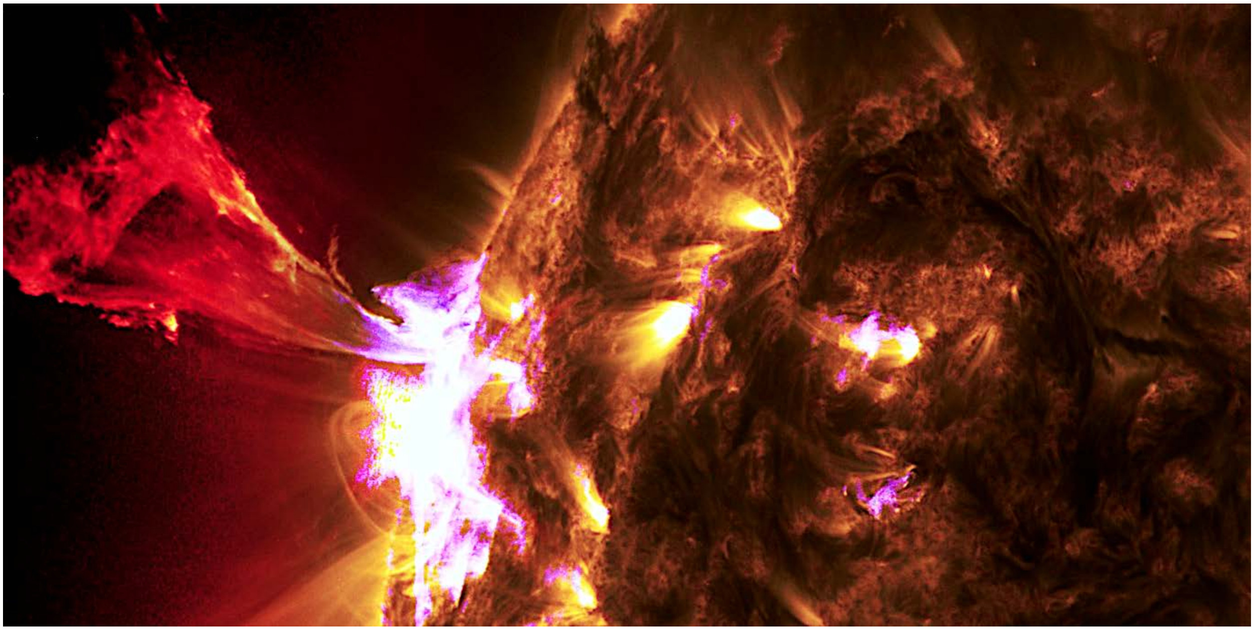
FIVE KEY DEFINITIONS

PLASMA:	*Electrically charged particles like electrons (-) or ions (+); Ions are atoms that have had electrons stripped from them. Familiar examples of plasma include fire, lightning, the Sun*
IRRADIANCE:	*Light. In this book, mostly referring to the sun's Ultraviolet and X-ray waves.*
FORCING:	*Influence, modulation, impact, etc. over a condition(s).* *Ex: Solar Climate Forcing (Sun's Influence on Climate)*
SPACE WEATHER:	*Earth's interactions with irradiance and plasma from the sun, supernova, other energetic events in space.*
ANTICORRELATED:	*It goes by many names: Anticorrelation, inversely correlated, indirect correlation, negative correlation. It means as one goes up, the other goes down – it does NOT mean "no correlation."* *Ex: Sunshine and brightness are directly correlated* *Sunshine and darkness are anticorrelated* *Strawberry size and Pluto's orbit have no correlation*

Ok, you're ready.

Introduction:

Despite the thousands of years in which humans have looked at the sun, studied it, and even worshipped it, we have learned more in the last two decades than in the previous millennia combined. Data and images from satellites such as the Solar Dynamics Observatory (below) have allowed us to literally see our star in a new light, as we can see in numerous ultraviolet and x-ray wavelengths. Most importantly, these satellites have opened the door for progress, understanding, imagination… and controversy.



It takes a few seconds to fall in love with the sun when seen through our best technologies, a few short hours to become significantly knowledgeable about what you are seeing, and a lifetime to get bored with it.

Despite the infancy of the science of studying the sun at this level of detail, there are already many public resources available. In addition to data portals from government organizations, including NASA (USA), NOAA (USA), ESA (Europe) and IPS (Australia), there are numerous resources like our free one- www.SpaceWeatherNews.com, designed with simplicity in mind.

There are millions of people who have already discovered the power and beauty of our star, and they are making a big difference in the development, perception, and popularity of the field. If two heads are better than one, then millions of enthusiasts are essential to the handful of scientists who would otherwise be working alone.

With widespread interest and involvement come problems. For example, there are few sciences that are as misunderstood as solar-terrestrial interactions; the interplay of heliophysics (study of the sun), and geophysics (study of the Earth). Most of the correlations, connections and patterns that describe how space weather affects our planet could not have been conceived just two decades ago, let alone some more-recent studies that detail the mechanisms by which these events modulate our climate, short-term weather, technology, health, seismicity and volcanism.

This book includes 1) the solar-terrestrial physics already in the mainstream lexicon, 2) the best ideas making their way around the journals, and 3) what diligent observations can teach us in the interim.

Many things make this field of study difficult, not the least of which is that it requires an interdisciplinary understanding. However, an equally frustrating aspect of this field is the overbreadth problem. If you are a lawyer, overstatements of fact and overreaching of conclusions gets you no points with a judge, but in a world in which your grants, your job, and your life depend on publishing, exposure, and even headlines, the tendency to go too far appears attractive to many.

On one hand: We've seen papers identify a weak cyclical period on Earth match a strong one on the sun and declare a grand correlation.

On the other hand: We've seen situations where a scientist fails to find a correlation between one of the dozens of solar factors and something specific such as average daily temperature in Moscow, and then proceeds to claim that the sun does not appear to affect climate change at all.

You can see how each of those studies may have value in what was observed and analyzed, even though their conclusions go further than the data should allow.

Another good example of this would be looking at your pointer, middle, ring, and pinky fingers and saying, "80% of my fingers are not thumbs; therefore, there is not a strong relationship between thumbs and human hands." If you can understand that example and how silly of a statement it is, despite the fact that the statistics are technically correct, you will do just fine with this book.

You are going to learn about the sun, how it sends energy to the Earth, how the Earth handles that energy, and how the sun is modulating everything from day-to-day storms to major earthquakes to heart attacks. More importantly, you will be given a list of resources that you can use to be part of the process and begin observing the sun and Earth relationship for yourself. The field of space weather is a practical culmination of astronomy, physics, and chemistry, and it is poised to become one of the most important and fastest-growing fields of science over the next 20 years.

- Ben Davidson, Founder, Space Weather News & The Mobile Observatory Project

On the Future of Weather Forecasting:

Picture it is 2030- you wake up and have your morning coffee or breakfast, and you turn on the local weather forecast.

Your meteorologist is discussing solar wind and how it could affect the weather in your area, or showing cosmic ray readings relating to a hail storm forecast for that evening. They may be showing different tracks for a tropical storm and describe how one track is forecasted if the sunspots on the sun release large solar flares, and how quiet solar activity means the other track of the storm is more likely.

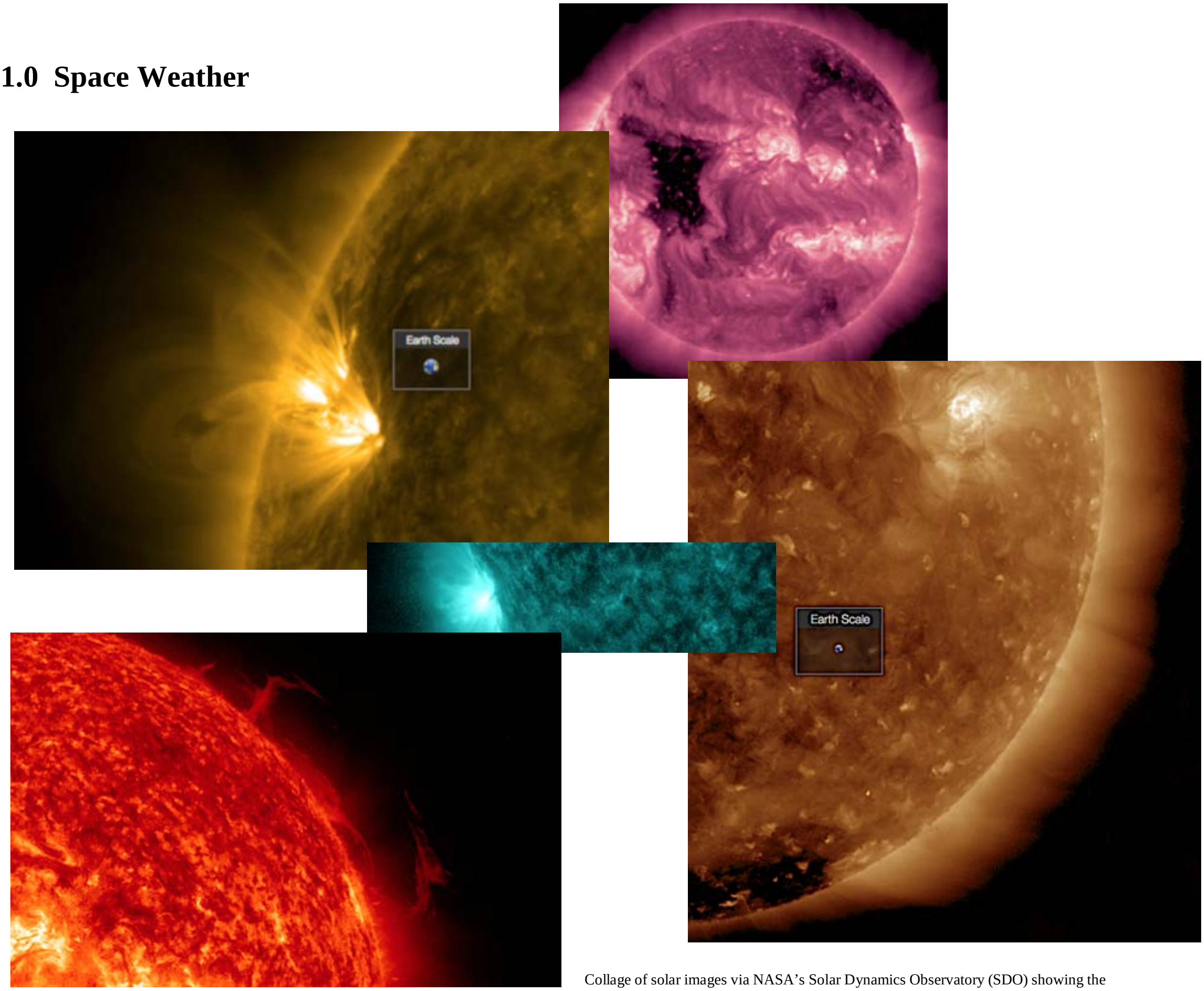
The forecast may include more than the weather- perhaps there will be forecasts for technological performance of your devices, outlooks for those with certain health conditions, and even warnings of earthquakes. Imagine if your meteorologists could warn you of high-cardiac-risk space weather- perhaps you wouldn't ignore that heavy feeling in your chest that day. What if you could receive mental and cognitive health alerts based on Jupiter-sized x-ray explosions on the sun? What if your meteorologist could show you electric activity in the atmosphere and forecast the seismic risk for your location?

Many of those things are already happening on a daily basis – it is merely not yet likely to be found on the news we have all been watching for years.

This book details a lot of what will come with the future of meteorology and how you can find it NOW. This book is your introduction to that world, at a level you can comprehend, and to a degree that 99% of professional meteorologists do not yet know and understand.

You are about to be ready for tomorrow's weather forecasting… today.

1.0 Space Weather



Collage of solar images via NASA's Solar Dynamics Observatory (SDO) showing the ultraviolet and x-ray environment of the sun's atmosphere.

The sun is much more than the star that gives us light each day. The sun's output spans the entire electromagnetic (EM) spectrum and includes particle radiation as plasma and neutral particles. Below is a basic chart of EM energy waves, some basic information about them, and how the sun operates at those spectra.

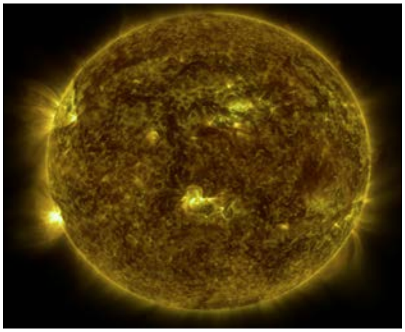
EM Spectrum	Solar Events	Ionizing?	Damages DNA?
Gamma Rays	Rare, Major Solar flares	Yes	Yes
X-Rays	Solar Flares	Yes	Yes
UV Rays	~Constant EM Solar Output	Sometimes	Yes
Visible	~Constant EM Solar Output	No	Rarely
Infrared Waves	~Constant EM Solar Output	No	Very Rarely
Microwaves	Variable EM Solar Output	No	Very Rarely
Radio Waves	Variable EM Solar Output	No	Very Rarely

Gamma rays are the highest-energy EM waves; radio waves the lowest. These are all photons (light). The EM spectrum, or type of wave/ray, simply describes the energy of that photon.

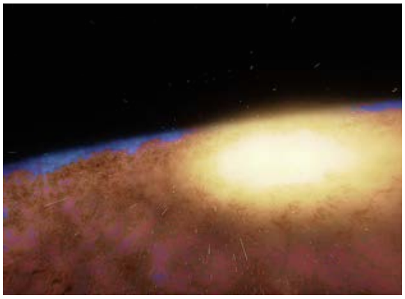
The sun operates across the entire spectrum of electromagnetic wave energy, and space weather is partially about the fluctuations of the sun's energy output at these various wave/ray level emissions.

The other type of emission required for understanding space weather is the particle side. Below is a basic chart of the most-important particles at play in space weather; they do not all come from the sun.

Type	**Particle**	**Charge**	**Energy Level**
Solar Wind	**Protons**	**+1**	**Low - High**
	Electrons	**-1**	**Low - High**
	Ions	**+1 and Higher**	**Low - Moderate**
Cosmic Rays	**Solar Energetic Particles**	**+1 or -1**	**High - Very High**
	Galactic Atomic Nuclei	**+1 and Higher**	**Low - EXTREME**
	Van Allen Relativistic Electrons	**-1**	**Low - EXTREME**



The sun is the source of nearly all relevant EM energy waves Earth receives in terms of the weather, and it is the source of the solar wind- a flow of charged particles constantly leaving the sun in all directions. The solar wind characteristics near Earth are determined by other solar features we will learn about in this chapter. The sun also produces higher-energy proton/electron bursts called solar energetic particles, considered to be cosmic rays.



The Milky Way galaxy and rest of the universe is the primary contributor to the cosmic ray spectrum. The majority of galactic nuclei, which are protons and atoms entirely stripped of electrons (+ charge), come from supernova and other energetic events in deep space. Cosmic rays are critical because they decay into other particles, and the strongest of them can reach Earth's core. We will discuss these more later in this chapter.

(Top) SDO image of the sun from NASA.gov. (Bottom) View of the milky way from an animation by the European Southern Observatory (ESO).

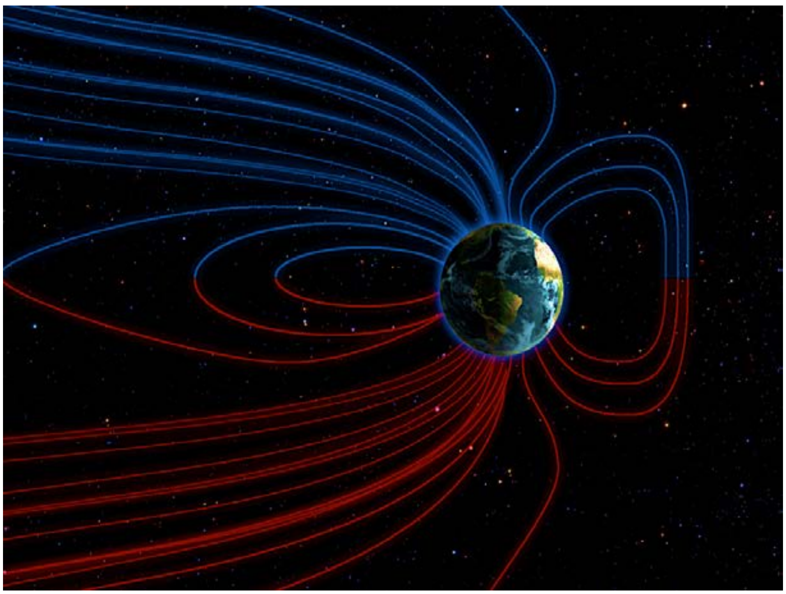
This book is meant to be an introduction to the Earth/sun interplay in **meteorology and climate**, so diving deeply into the microphysics of space weather is outside its context. However, it is necessary to have a basic-intermediate understanding of the terminology, processes, and important events affecting the relationship between us and our star. This is the purpose of Chapter 1.

It is also essential that you know the layers of the Earth involved in the interaction with solar energy. These include the magnetosphere, the ionosphere, the atmosphere, the crust, and the mantle. The next chart describes these layers and their basic space-weather interactions, starting with the highest (outermost) layers and coming down:

Earth Layer	**Description**	**Solar/Cosmic Influence**
Magnetosphere	Global magnetic bubble	Almost all space weather affects it
Ionosphere	Layered ion sheets	Almost all space weather affects it
Atmosphere	Layered gas volume	Much of space weather affects it, secondary effects*
Lithosphere	The ground around us	Very-high energy particles, secondary effects*
Mantle	Liquid rock way way, down	EXTREME particles, secondary effects*

* "Secondary effects" refers to the coupled effects resulting from space weather-driven changes in the layers above; we will learn about the geomagnetic storms and cosmic rays that produce these effects later in this chapter.

Here is a bit more information about the layers:



Magnetosphere - Earth's Magnetic Shield

What *would* look like a spherical bubble 1000s of miles around our planet appears like this in profile view, with the sun off to the right. The compression facing the sun is because the solar wind blows-back the field into this shape. The magnetosphere is the primary shield against electromagnetic waves and charged particles. Both polar and low-latitude field loops are seen here.

Ionosphere - Earth’s Electric Layers

Starting at the top of the atmosphere (altitude ~37 miles) the profile of the air becomes charged/ionic. The density of the particles drops and for more than 100 miles upward there is layer after layer of ions. These layers are called “D, E, and F1 through F4”, where the D region sits on top of the atmosphere and F4 is the outermost *known* layer, ~200 miles in altitude.

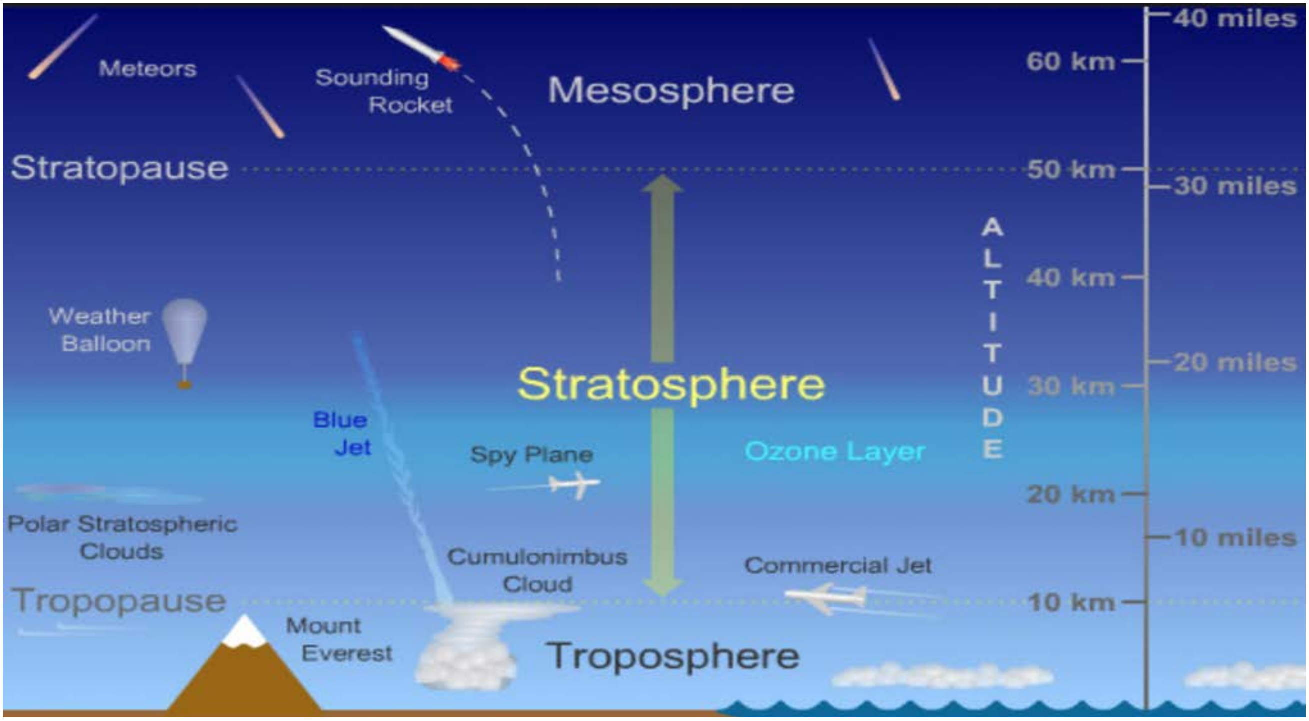
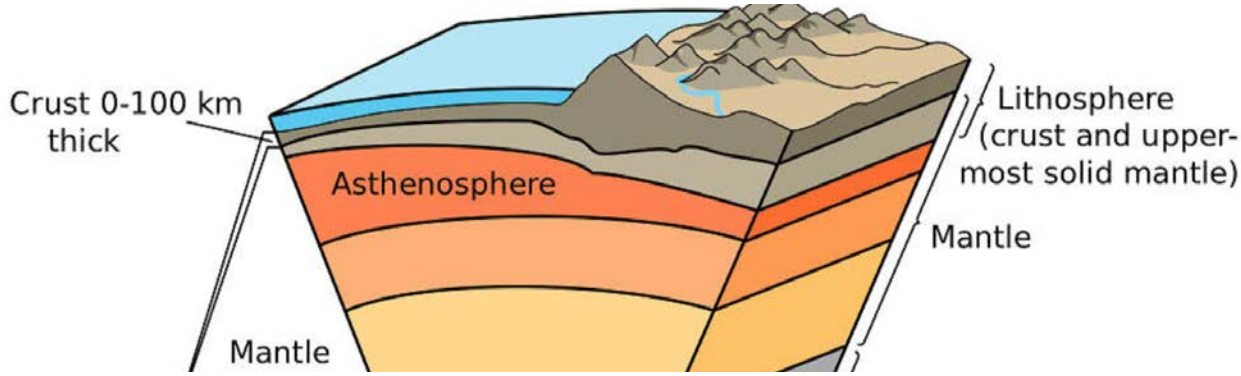


Image from NASA.gov

Atmosphere - Earth’s Gas Layers

Below the ionosphere are three atmospheric layers: the mesosphere, the stratosphere and the troposphere. The ozone layer is nestled in the stratosphere. All humans live within the troposphere. The atmosphere has increasingly lower density with higher altitude.



This image of the lithosphere (Earth's crust) and mantle is from the U.S. Geological Survey, USGS.gov, and shows the complex layering structure of the ground beneath our feet. The actual boundary between the lithosphere and mantle is somewhat ambiguous, in a region called the asthenosphere, where there is less homogeneity to the chemistry, viscosity, etc., and where strong electrical conductivity/anomalies are found.

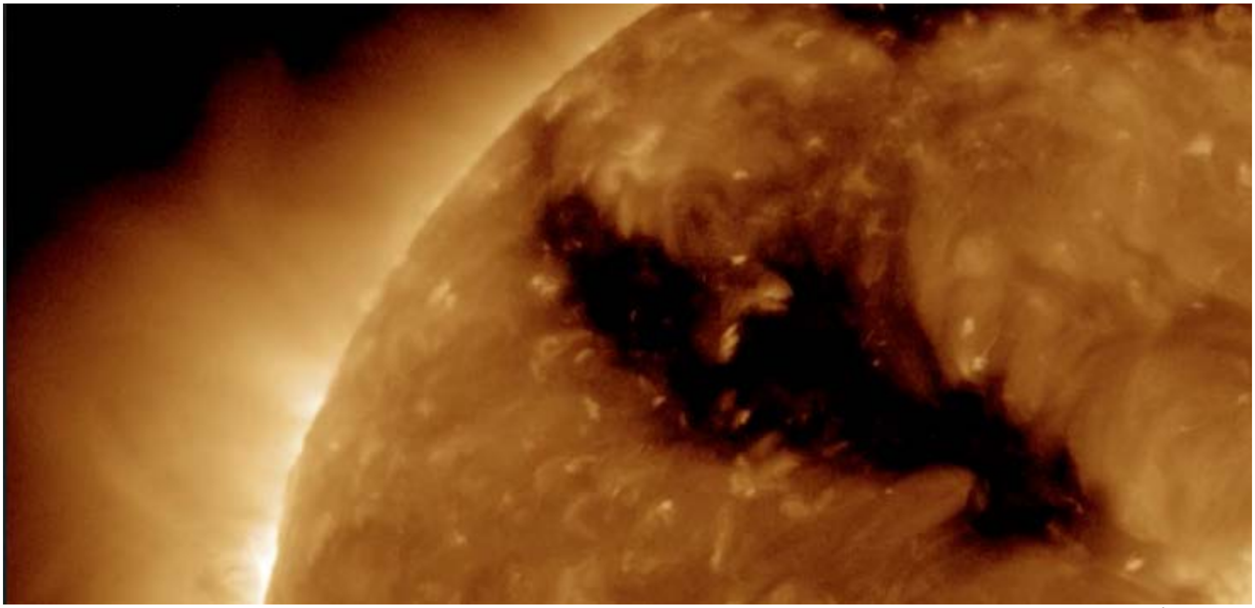
Key Points:

1) The sun emits electromagnetic (EM) radiation in the form of photon light (**waves**) at energies spanning the EM spectrum from radio waves to gamma rays.

2) The sun, galaxy and cosmos all contribute charged **particle** radiation that can interact with Earth.

3) The effects of 1) and 2) at Earth depend on their interaction with Earth's layers: Magnetosphere, Ionosphere, Atmosphere, Lithosphere and Mantle.

4) Earth's magnetic fields is pushed away from the sun by the solar wind, molding the spherical field into a compressed sun-facing side and far-streaming night-side.



SDO image of the sun.

1.1 Solar Wind

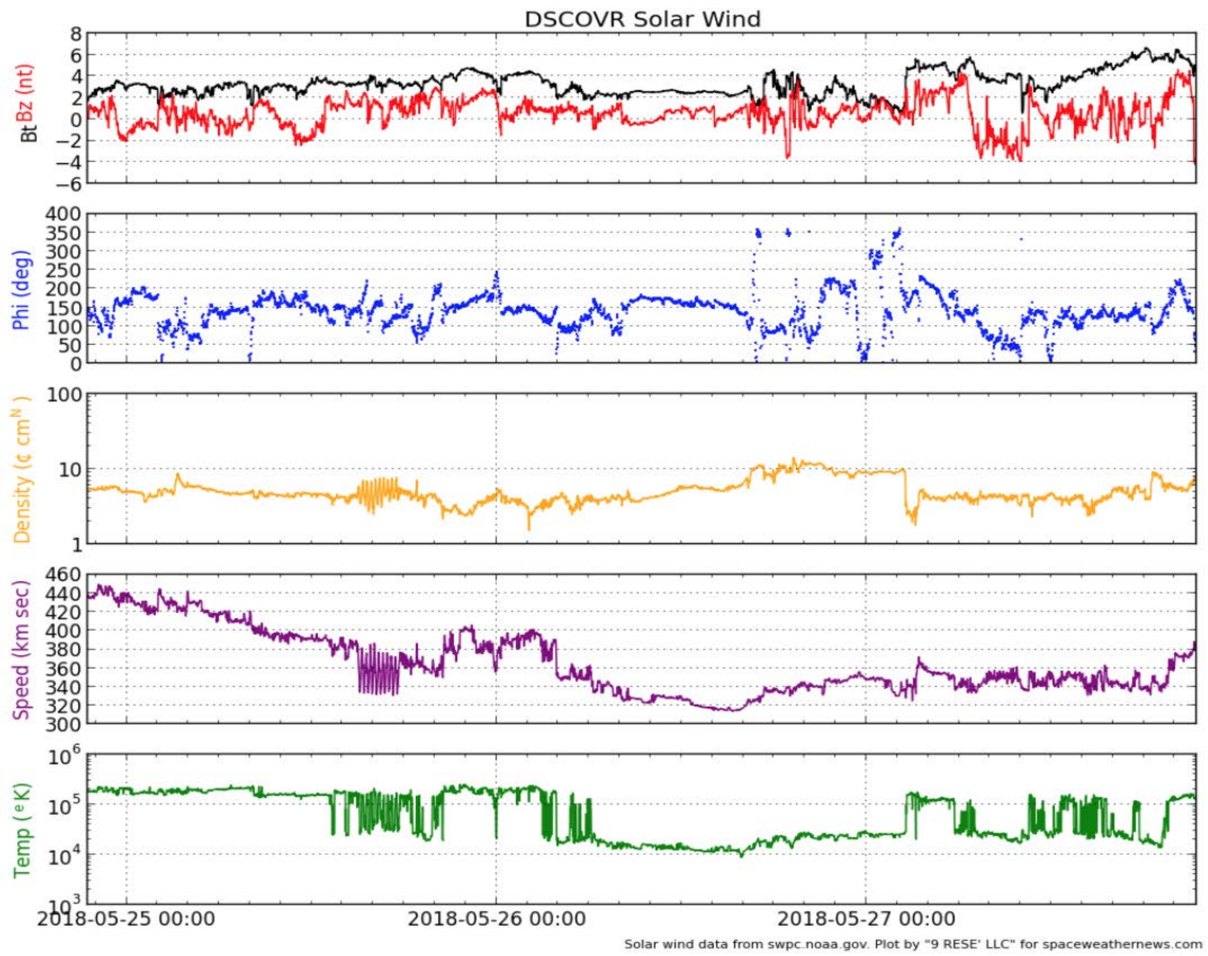
The first subject everyone must learn about space weather is the solar wind, the charged particles constantly streaming away from the sun in all directions, all the time. The solar wind streams out past Pluto where it slows down and stops in the outer reaches of the solar system. NASA's Genesis mission discovered that nearly every known element can be found in the solar wind, but most are there only in trace amounts. The majority of the solar wind is made up of +Hydrogen ions, electrons, protons, and some neutral elements like Helium. The solar wind creates a field of plasma that surrounds the solar system. What does this mean?

The solar wind streaming outward, through and surrounding the solar system, is an electric field of charged particles- plasma. These solar wind particles race away from the sun in various densities, ranging from a few particles per cubic foot to dozens, hundreds, or even thousands of particles per cubic inch, especially as the solar wind slows down near Mars, bunches up, and becomes extremely dense.

At Earth, the speed of these particles whizzing past Earth generally ranges between 200 to 275 miles per **second** (*not* miles per hour!) during normal quiet times, but can spike to over 600 miles per second, which is more than 2 million miles per hour, during major space weather events. Solar wind density and particle speed are usually given in metric units, so 300 to 400 kilometers per second (km/sec) would be average speed, along with average density of 0.1 to 10 protons per cubic centimeter (p/cm^3).

More intense streams can exceed 800 kilometers per second and can be dozens to hundreds of protons dense per cubic centimeter. These intense portions of solar wind tend to be hotter by a factor of 10 to 100 (usually given in Kelvin scale) and can also have drastically different impacts in terms of their magnetism and angle of approach, which creates various interactions with the Earth and its various electromagnetic layers, especially the magnetosphere and ionosphere.

The image below displays solar wind telemetry from the DSCOVR satellite for May 25 - May 27, 2018, with a description below.



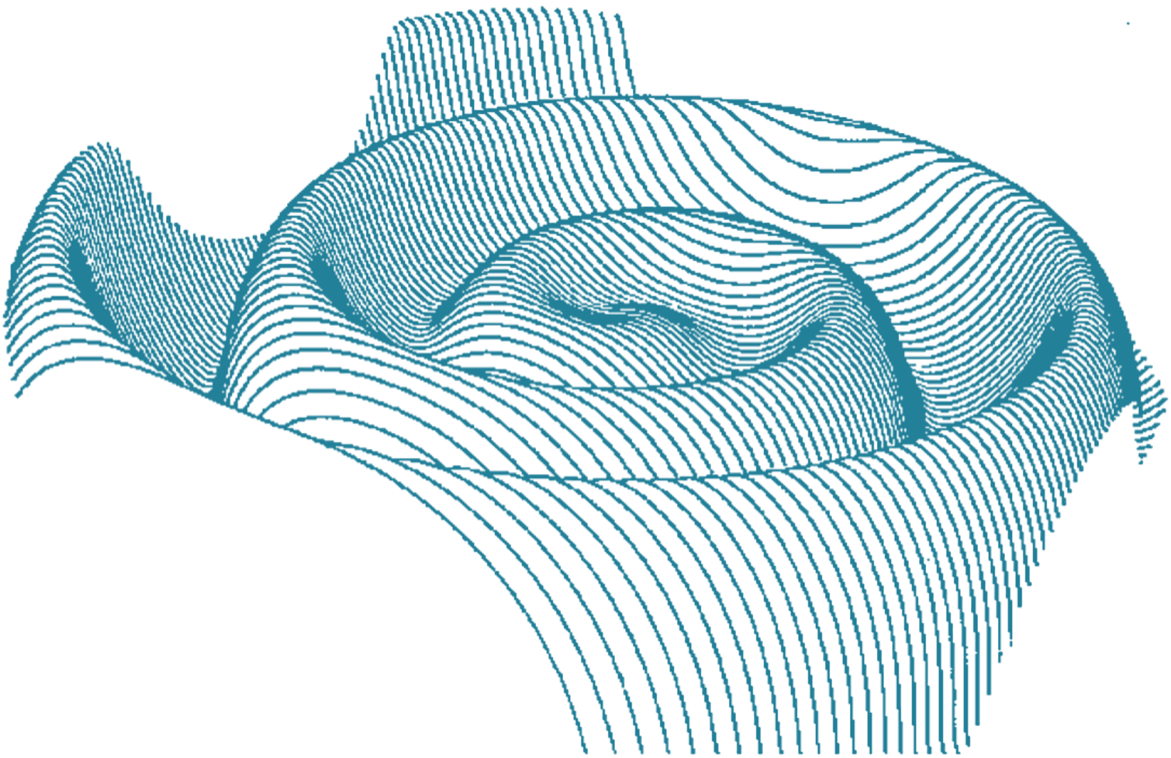
The bottom three panels tell us what kind of space weather we are experiencing: the solar wind density (orange), speed (purple), and temperature (green) are also labeled on the y-axis. In this image, we see solar wind speed decreasing from about 450 km/sec to about 350 km/sec, indicating a faster solar wind stream was ending during this time, at relatively normal density, accompanied by the return to normal calmer speeds. Even the faster stream was not very extreme, since solar wind speed above 600 km/sec is considered fast, and this stream was just barely over the normal average range ceiling of 400 km/sec.

The top two panels are a bit more complex. The blue “Phi angle” of the solar wind indicates the magnetic field direction (a topic we’ll discuss soon), where ~180º changes offer intensity fluctuations similar to those caused by a dense/fast solar wind stream. The top panel (red, Bz index) shows the power of the stream and likeliness to affect Earth’s magnetic field. While the absolute magnitude of the Bz (“Bt” – black line) tells us about the power of the solar wind, the negative numbers on the red curve, known as south-facing polarity, have a stronger effect than positive (north-facing) polarity streams of solar wind. Positive Bz solar wind is more-easily deflected by earth’s magnetosphere, while negative Bz streams tend to merge or ‘couple’ with the earth system.

In other words, magnitude isn't the entire story, magnetism matters too. Negative (south) is likely to couple, integrate, disrupt, etc. This plays a critical role in whether the solar wind is significantly influencing the rest of the Earth's layers below.

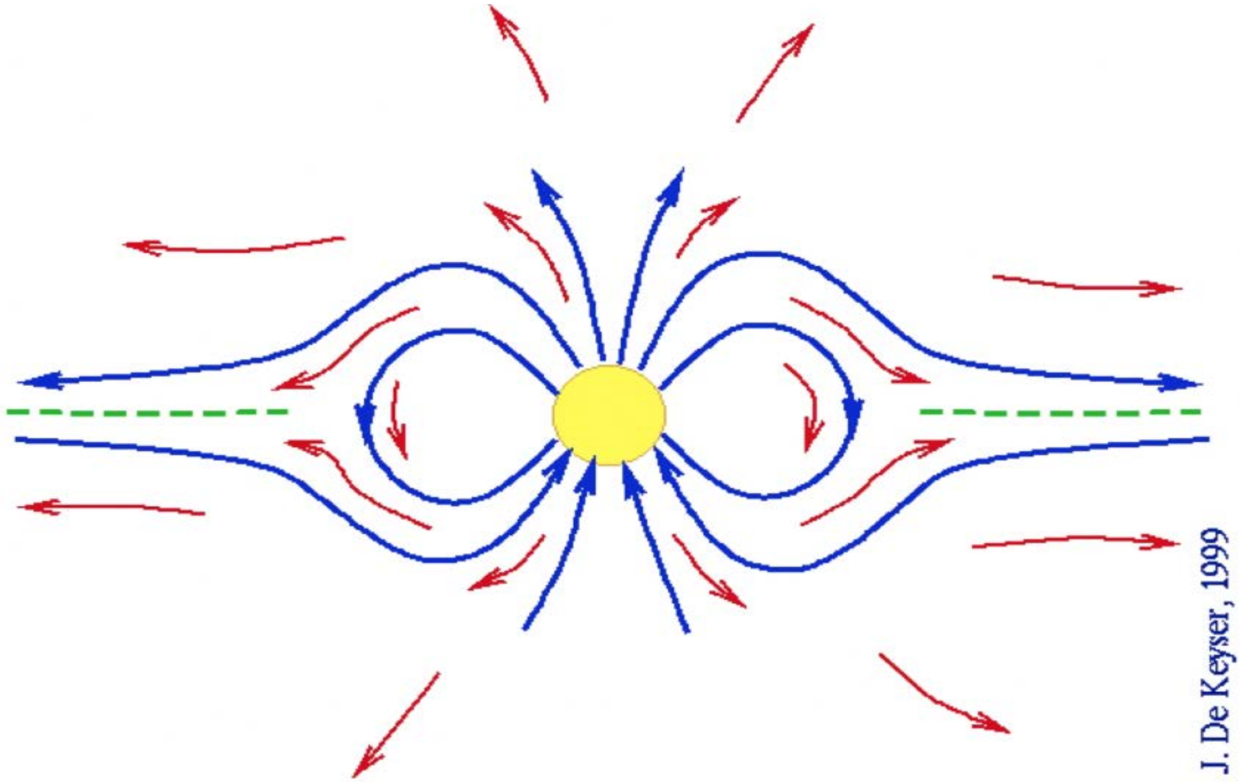
The differences between the quiet and intense streams of solar wind are central to studying and monitoring space weather. Solar flares and coronal holes (described later in this chapter) can intensify the normal solar wind, delivering "interplanetary shockwaves" and "high-speed" solar wind streams that affect the different layers of Earth directly and indirectly. The secondary (indirect) effects are critical to this book, and often have lagged-forcing effects over days to years, which means that the primary effects might be seen rapidly, or not for some time after the solar events.

Heliospheric Current Sheet – The Solar Wind Electric Field: The particles moving away from the sun create a streaming sea of charged material and plasma. This field of solar wind particles encompasses the entire solar system and technically means that outer space is not a true vacuum. The solar wind and trace dust/gases are divided into north and south, and the region between them makes up the "heliospheric current sheet". Here is a view of the current sheet dividing north and south:



Heliospheric current sheet of solar wind from wind.nasa.gov.

With the sun in the center, the all-directions-outward solar wind is not depicted in this image, but rather the quasi-equatorial boundary between the *magnetic* north and south hemispheres of the solar system is shown by that wavy, rippling field. This boundary separates the magnetic field direction of the interplanetary magnetic field, which is different than the solar wind electric field. The next image looking edge-on at a slice of the sun's current sheet should help explain:



In this graphic, the sun is in the middle, the red arrows show the solar wind streaming out in all directions, but the blue lines show the sun's largest magnetic fields, which go out through the solar system. Just as Earth's fields connect point to point on Earth, they do so on the sun - but often the sun's fields go out past Pluto before reconnecting. The "heliospheric current sheet" from the previous image is contained within the equatorial zone (green), where all magnetic fields north flow one direction and all fields on the south oppositely. If we could zoom out from this graphic the green line would begin to wave and ripple like we saw in the previous image.

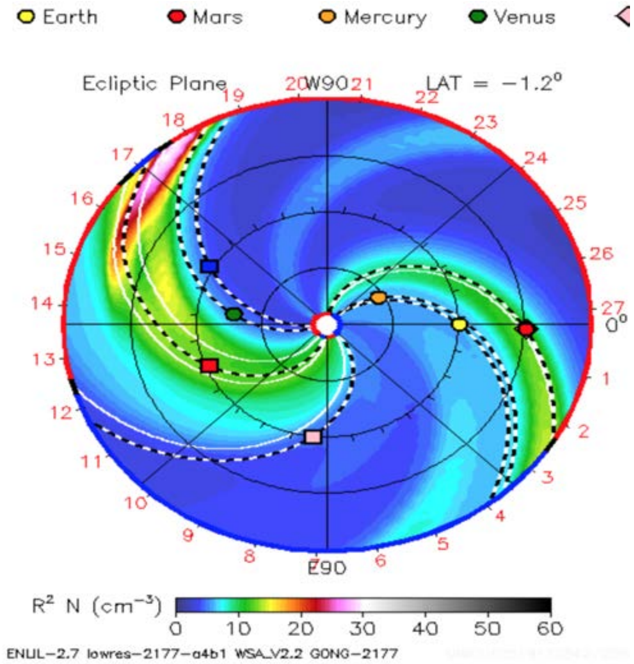
The field flow pattern (blue) reverses on the sun every 11 years, so the specific direction and its placement north or south depicted here are arbitrary.

Due to the fact that the sun spins in ~27 days, the heliospheric current sheet zips around the solar system much faster than the planets are orbiting. All the planets in the solar system spend time above and below the undulating current sheet in their orbit; each crosses that rippling field.

Electromagnetic Interaction. The sun and planets are sphere magnets, with either intrinsic or induced magnetic fields existing in some form at each of the planets. This causes a direct magnetic connection between the planets and sun to arise within the electric field of solar wind. This magnetic connection acts like a wire connecting the spheres, or perhaps better-imagined as a path of least resistance through an electrified medium.

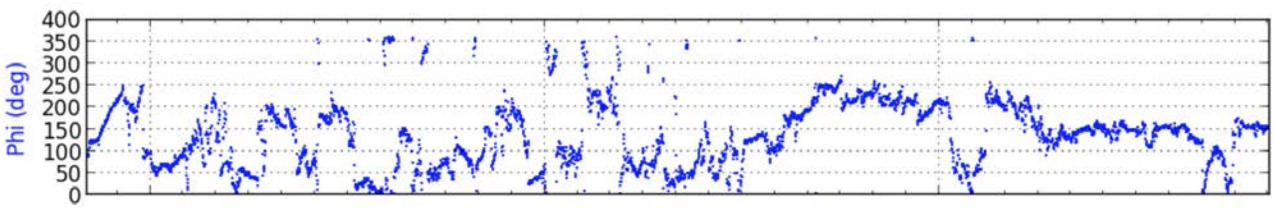
These connections of planet-to-sun are called interplanetary magnetic fields (IMF), and they can drive charged particles across space at incredible speeds, bypassing a planet's defenses against space

energy (magnetosphere), and allowing solar wind to pour into the atmosphere. We see this on Earth **every eight minutes** in energetic exchanges called flux transfer events (FTEs), and on other planets on different timescales. The amount of energy exchanged is not always the same (Section 1.7).



This image is from the National Solar Observatory and is called the ENLIL spiral (Enlil was the Sumerian god that controlled the wind and gave the breath of life). The colors show the density of the solar wind in the Earth's orbital plane, looking from above (north). It also shows the IMF connecting the planets and sun, (black and white dashed lines bending with the rotation of the system). When a big solar event occurs, we can track its effects on the solar wind throughout the solar system with the ENLIL spiral, as well as determine if Earth's magnetic connection to the sun was directly affected by the big event, which would add to the potential space weather effects.

The Phi angle of the solar wind tells us whether Earth is above or below the heliospheric current sheet, and whether the IMF is flowing to the Earth from the sun or is feeding back to the sun from the Earth.



Phi angle is measured in radial degrees, as you would mark them around a circle; while the scale in the image above goes up to 400, you will never see it above 360. 0 & 360 degrees are actually the same thing on a radial graph, and that field angle indicates that the IMF is streaming directly back at the sun from the Earth. When the IMF Phi angle is 180 degrees it indicates that the IMF is streaming directly towards Earth from the sun. The solar wind plasma field always streams outward; the plasma travelling along the IMF can go both ways.

The following sections of this chapter involve solar phenomena that affect the solar wind, the heliospheric current sheet, or the IMF, and therefore have a chance to affect the Earth as well.

Key Points:

1) The sun’s charged particle emission, known as the solar wind, is an electric field of particles streaming out through the entire solar system.

2) Every known element has been discovered in the solar wind, but it is primarily comprised of protons, electrons, and the nuclei/neutral atoms of Hydrogen and Helium.

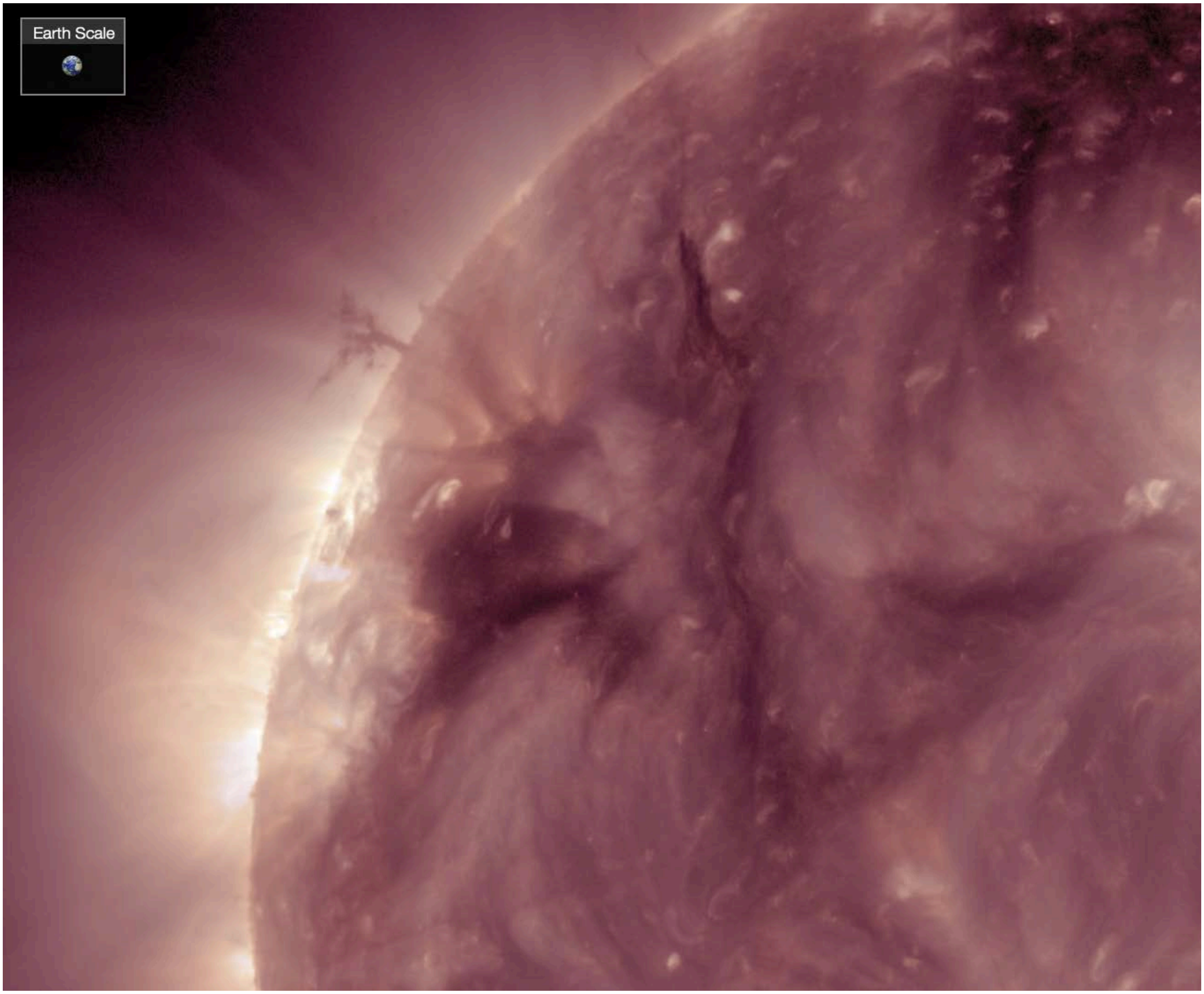
3) The solar wind is magnetically separated into north and south hemispheres of the solar system, with the equatorial zone undulating above and below the heliographic equator, and the orbits of the planets, allowing them to pass through the “current sheet” of solar wind as the sun rotates.

4) The IMF streams out through the solar wind, and forms a large-scale circuit connecting back to the sun from the far reaches of the solar system, streaming in both directions, away from and towards the sun.

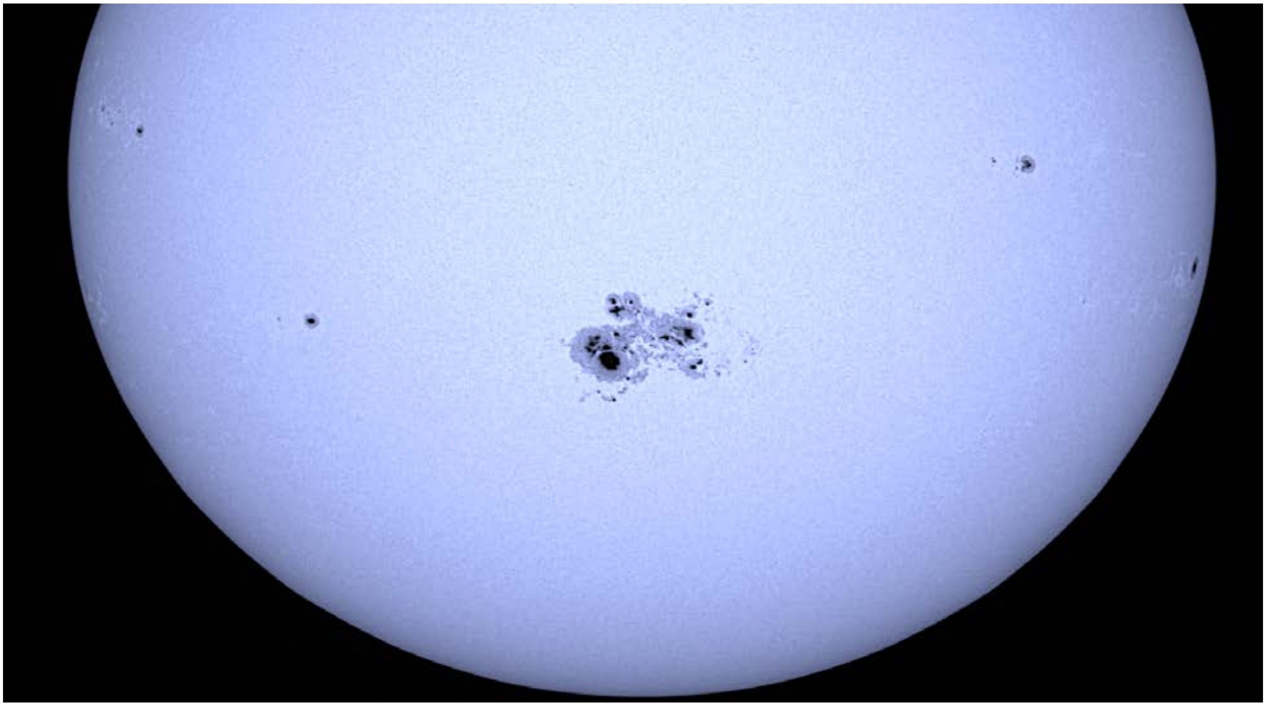
5) Planets ‘magnetically connect’ to the sun directly via the interplanetary magnetic field (IMF). The sun and Earth exchange plasma along these fields every 8 minutes in a “flux transfer event.”

6) The primary characteristics of importance in the solar wind are the density, speed, temperature and magnetic angle of the streaming particles.

7) Bz of the solar wind indicates the power of the solar wind; negative Bz is more effective on the Earth.



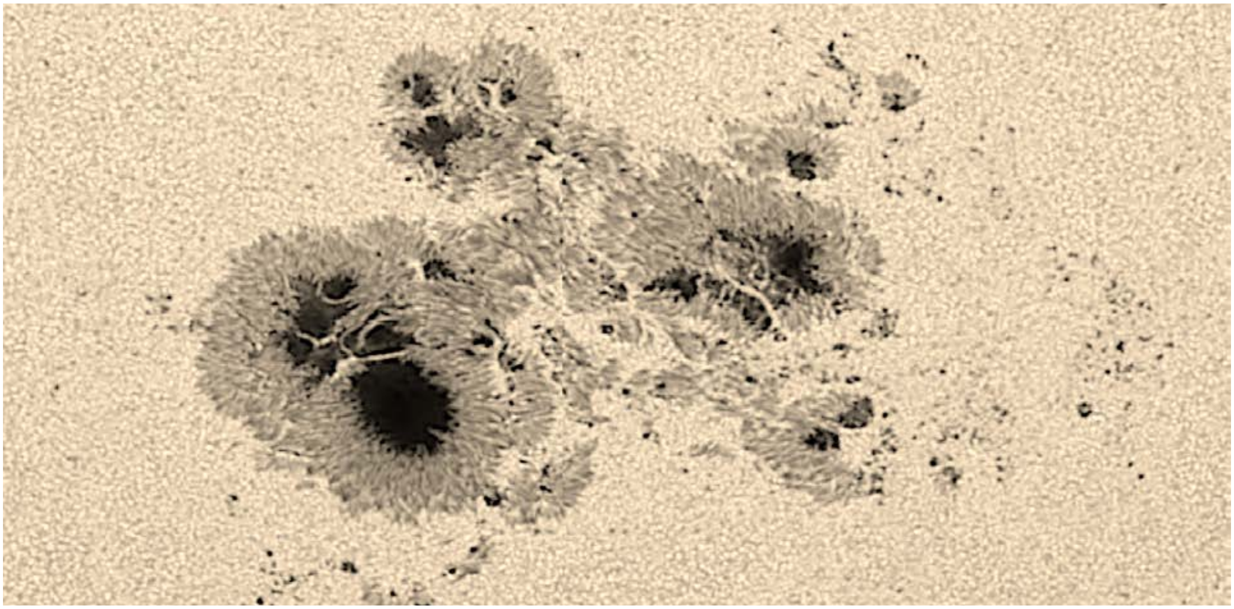
NASA.gov SDO/AIA 211 & 171



SDO image of the sun’s photosphere, showing sunspots. This is the HMI instrument, with neutral iron detection.

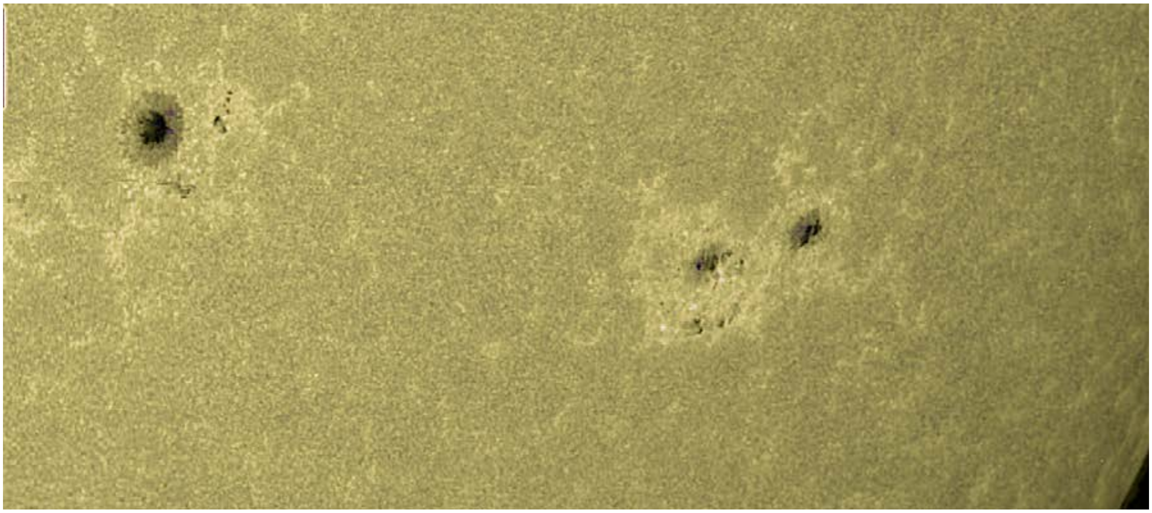
1.2 *Sunspots*

Sunspots have been studied for centuries; long before fancy satellites and telescope filters, humans were able to see sunspots and even keep records of their numbers. Sunspots are areas where electric current/magnetic fields enter and exit the **solar surface (photosphere)**, causing unstable areas in the **solar atmosphere (corona)** above and around them.

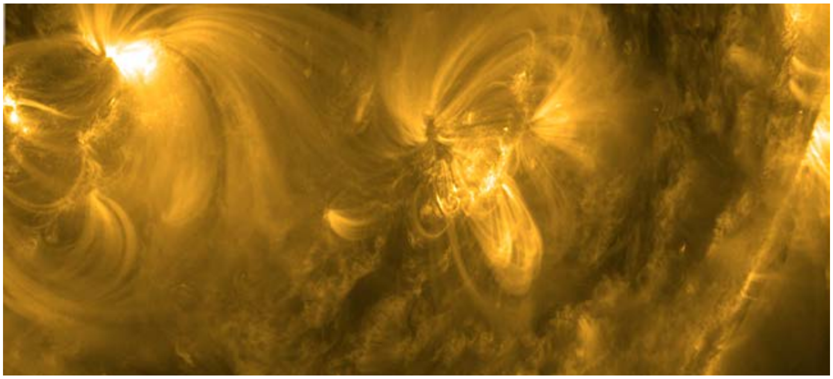


Zoomed-in image of the large sunspot in the image above.

The dark black cores of sunspots are called sunspot **umbra**, and the interface area surrounding the umbra is called the **penumbra**, which looks like filaments or hair streaming away from the umbra. The umbra is where current/magnetic fields enter or exit the surface of the sun. The penumbra is an electric effect at the surface (perpendicular to the currents and fields going vertically through the sunspot). The activity of these sunspots is key to understanding much of space weather.

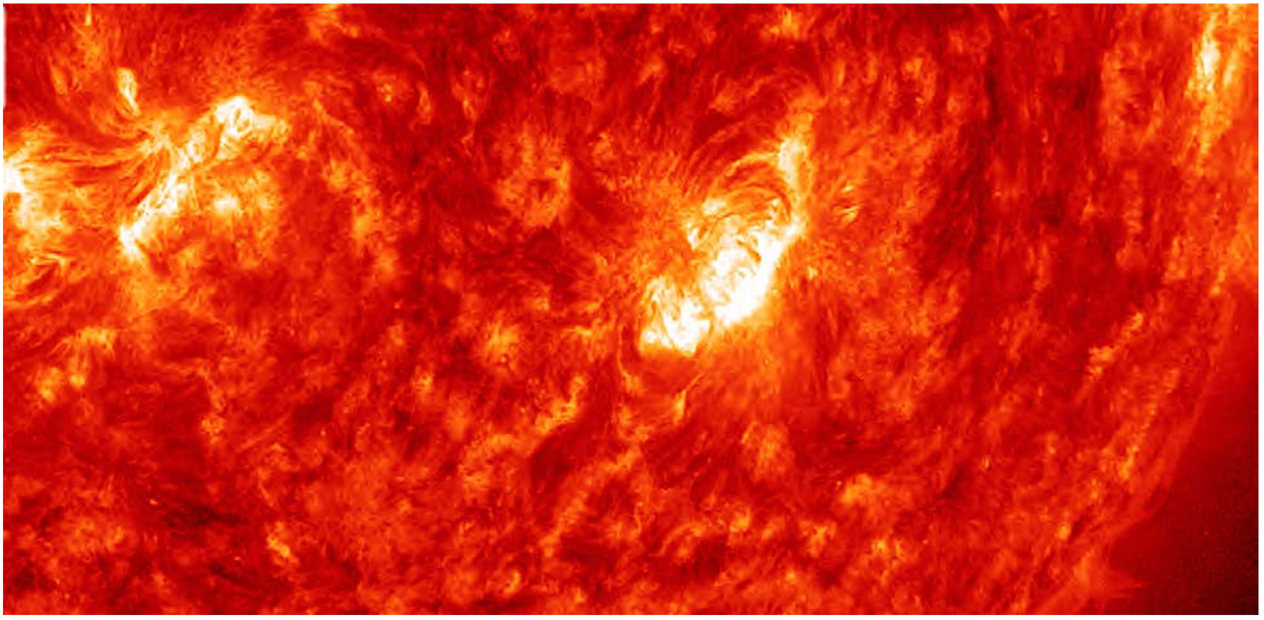


In the SDO image above we see multiple sunspot regions. The group on the right has two main umbral cores and small spots to the south of one of them, while the one on the left has only one main sunspot and small spots around it. Since the sun rotates left-to-right from our perspective, the far-right sunspot in a grouping is called the "leading spot" and the left side is the "trailing spot" or "spots". The small spots in the right-side group sit south of the "trailing spot". Sunspots like the ones on the right are extremely volatile and often contain numerous smaller sunspot umbra like the ones on the previous page. The sunspot on the left is less volatile; the explanation follows:



In the image to the right we see ionized Iron (171 Ångströms of light) trapped in the magnetic fields coming in and out of the same sunspots that we saw above. The arcs are "umbral magnetic fields". Unlike the IMF, which connect planets to the sun, umbral fields only connect the sun to the sun, doing so in loops, as you see here. We usually see a spot-to-spot connection, but they can also loop back down to areas of the surface that are magnetic. The single spot on the left side has too many fields to be contained within the smaller surrounding umbra, so it reaches out for other connection points towards the right-side sunspots. The right-side sunspots are much more contained in terms of their magnetic fields loops, because there are many sunspot umbrae to contain them, unlike the group on the left, which must reach out to connect. The large reach on the left is a stable scenario; the compact/complex field setup on the right is more unstable.

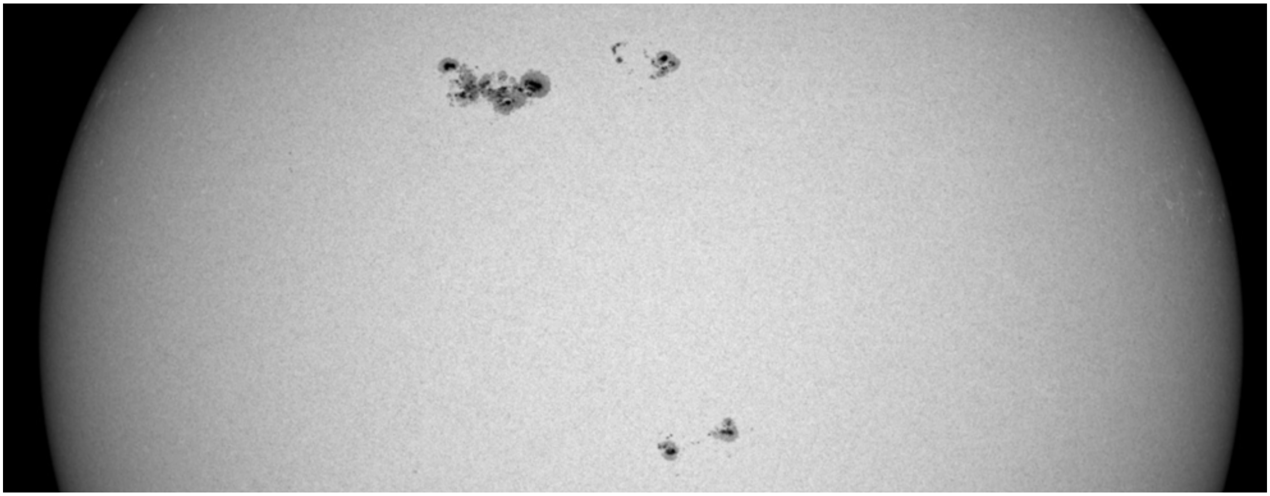
In the next SDO image (red) we see the same sunspot groups for the third time. Unlike the first two images, which showed sunspot umbra and umbral magnetic fields, respectively, the image below shows ionized Helium glowing in 304 Ångströms of light. The brightness indicates just how active and unstable the sunspot areas are compared to the rest of the solar surface and corona, and the superior brightness of the grouping on the right is due to its being more unstable and having more umbra compacted and confined to the small area of the group. At the three levels we've examined, we have learned that (1) many sunspots of different sizes, in complex arrangements, are the most unstable and at-risk (what that means is coming up in the next section), (2) that those at-risk regions have confined (rather than spread out and far-reaching) umbral magnetic fields, and (3) they shine brightly in 304 Ångströms, while they may not in 171 Ångströms. These are KEY components of gauging the risk of any given sunspot group.



You can interpret the brightness in this image to mean that more activity and interaction between the complex fields is taking place at the sunspot group itself. **The interactions of the plasma and ions in the regions above the sunspots are the drivers of the most exciting space weather event: the solar flare.**

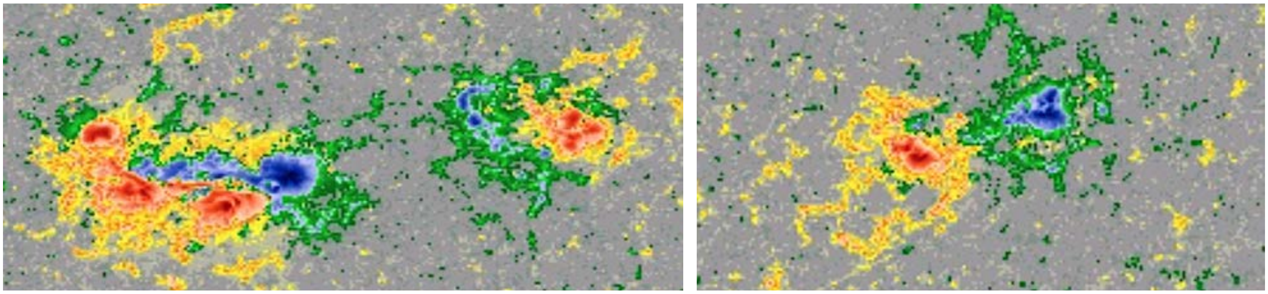
Note: Sunspots are a general indicator of the sun's activity and the character of the heliospheric current sheet. During times when there are lots of sunspots, we tend to see a denser and more intense electric field of solar wind throughout the solar system.

In addition to looking at multiple layers of a sunspot group to determine the likelihood of solar flares, this can be accomplished by looking at only the sunspots themselves. In the next images we compare the two types of images returned by the Helioseismic and Magnetic Imager (HMI) on the SDO satellite:



(Above) SDO HMI neutral iron image of a few sunspot groups.

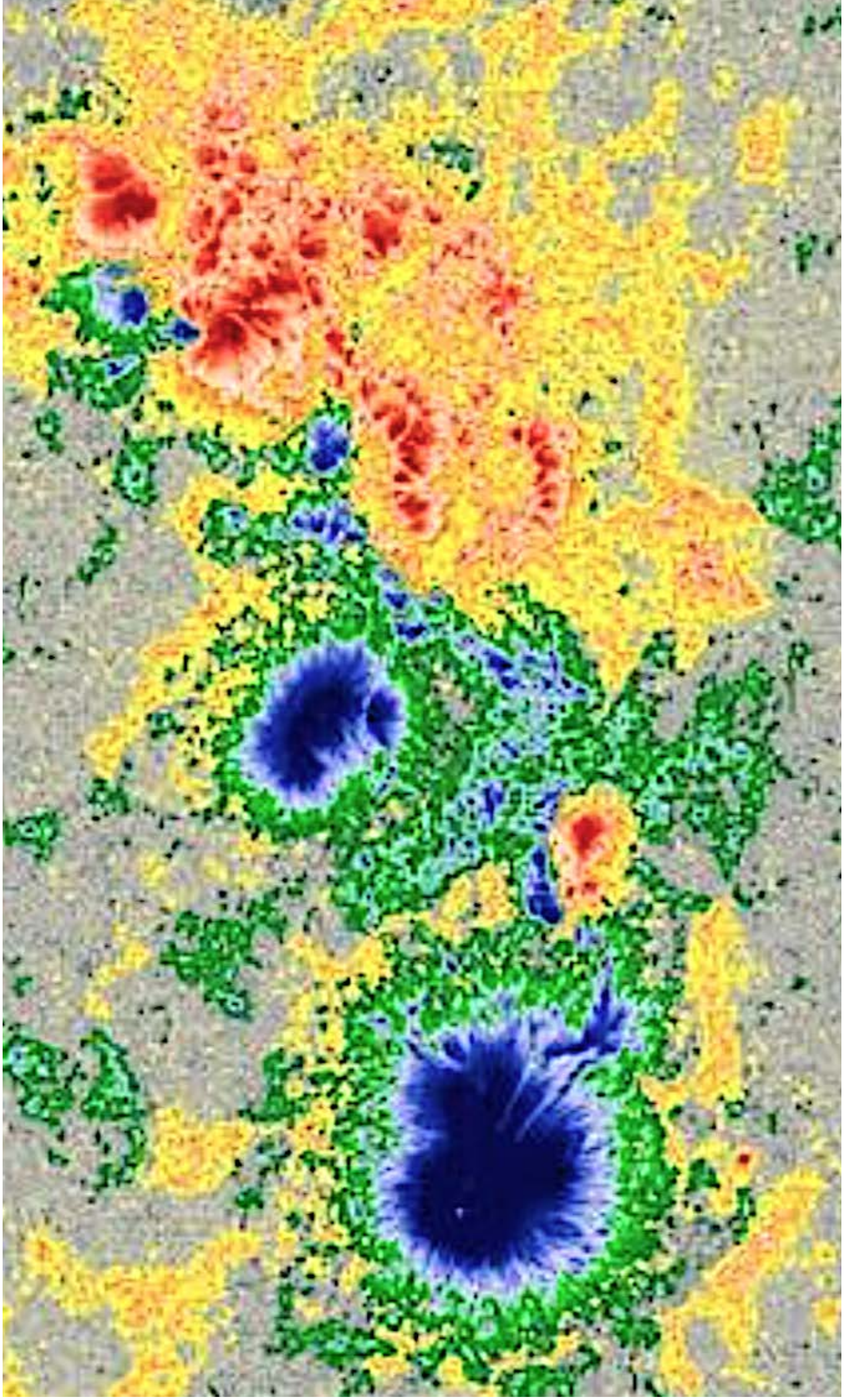
(Below) The HMI magnetic imager's close-ups of the northern spots (left) and southern spots (right).

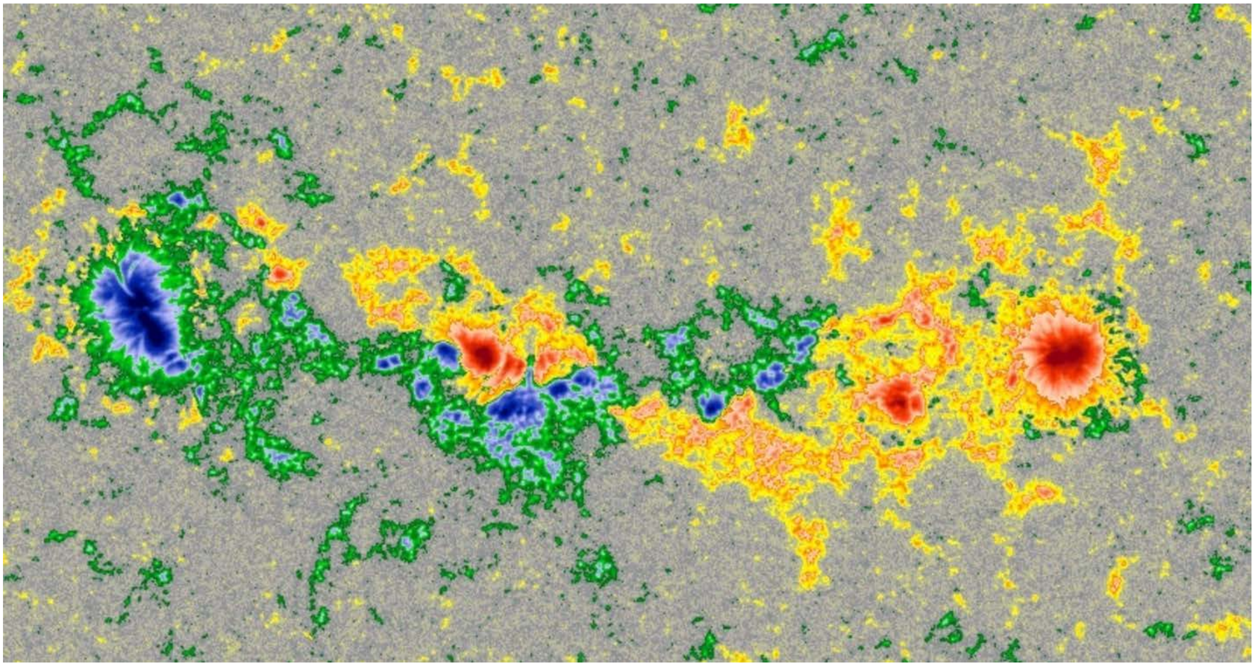


Blue shows positive polarity, red shows negative polarity - the umbral magnetic field loops always connect positive to negative. Lower-energy magnetic areas around the sunspots (yellow/green), are where less-contained and far-reaching umbral fields may connect if they do not have a sunspot with which to connect. One of the most reliable means of confirming the danger of a sunspot group is to find its “magnetic classification”. Sunspots may have more than one classification:

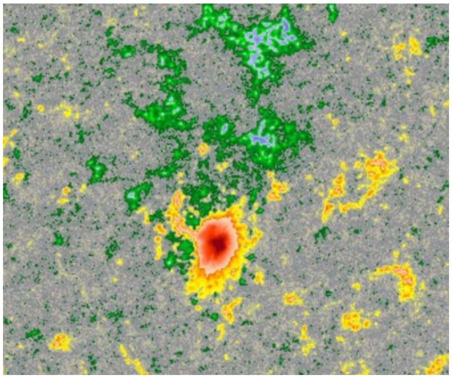
Magnetic Class	Magnetism Description	Solar Flare Risk
Alpha	One polarity (charge) only. All umbral fields connect to outside surface magnetism.	Low
Beta	Both positive and negative polarity spots found in the group.	Moderate
Gamma	Occurs in beta groups where a continuous line cannot separate the polarity groupings.	High
Delta	Where positive and negative spots share penumbra (close proximity).	Highest

All three spots in the images above are beta, and the one on the bottom far-left is also delta due to the stretch of close proximity spots of opposite polarity in the center (blue on top, red on the bottom). On the next page is a sunspot group that is beta-gamma-delta; it has both polarities (beta), the blue spot on top and the red spot near the bottom are separated from the rest of their like-polarity spots (gamma), and many “delta class” close-proximity regions exist down the middle. Delta and gamma classifications present the largest solar flare risks.



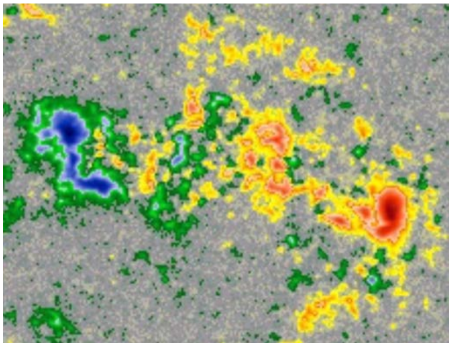


Above we find another example of a beta-gamma-delta sunspot group. It has both polarities (beta), regions where sunspots are cut-off from their larger group of like-polarity spots (gamma), and heavy interaction in the central region between red and blue (delta). It released numerous solar flares at the end of August 2017.



The image left shows an alpha class sunspot. All sunspots are going to have magnetic surface regions around them, but they will not count for magnetic classification of the active region unless they have proper umbra and surrounding penumbra.

Alpha class active regions are the least likely to be actively flaring, regardless of their size. The surrounding magnetic regions are the places to watch for further sunspot development, which may ultimately change the classification of the region, which may be the case here in blue to the north.



This image shows a beta class sunspot group, with the opposite polarity cores leading and bringing up the rear of the active region. The region in the center, where we'd watch for further development based on the surface magnetism, would be able to add gamma and delta classifications to the sunspot group with only a few hours of development. **Inactive sunspots can develop and begin flaring within hours.**

Key Points:

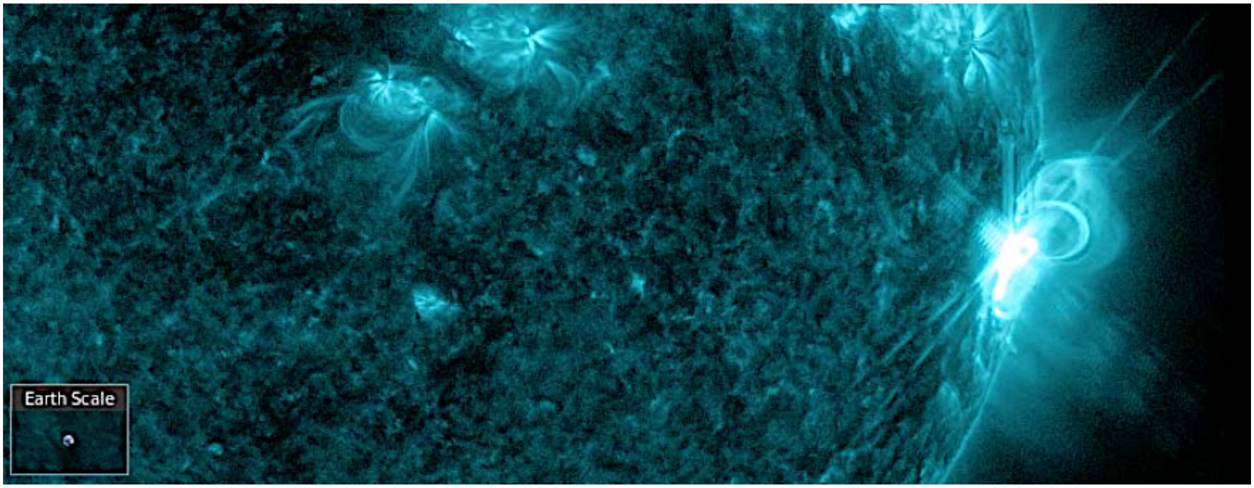
1) Sunspots are electromagnetic areas on the sun where plasma currents and magnetic fields enter and exit the surface of the sun. These umbral magnetic fields look like loops arching over the surface of the sun.

2) Sunspot umbra are magnetic (+ or -), and the currents/fields of a sunspot will **only** connect to a sunspot umbra or surface magnetic region of the opposite polarity.

3) Solar flares can be forecast by looking at the umbral magnetic field complexity, and the magnetic classification of the sunspot.

4) Sunspots with confined and complex fields, especially those with delta/gamma magnetic classifications, present the largest solar flare risks.

5) Beta sunspot groups may also carry a gamma or delta classification, but a spot may not have both alpha and beta classifications, and alpha spots also cannot carry gamma or delta classifications.



SDO Image of a solar flare (bright flash) during an incredible flurry of flare activity in September 2017.

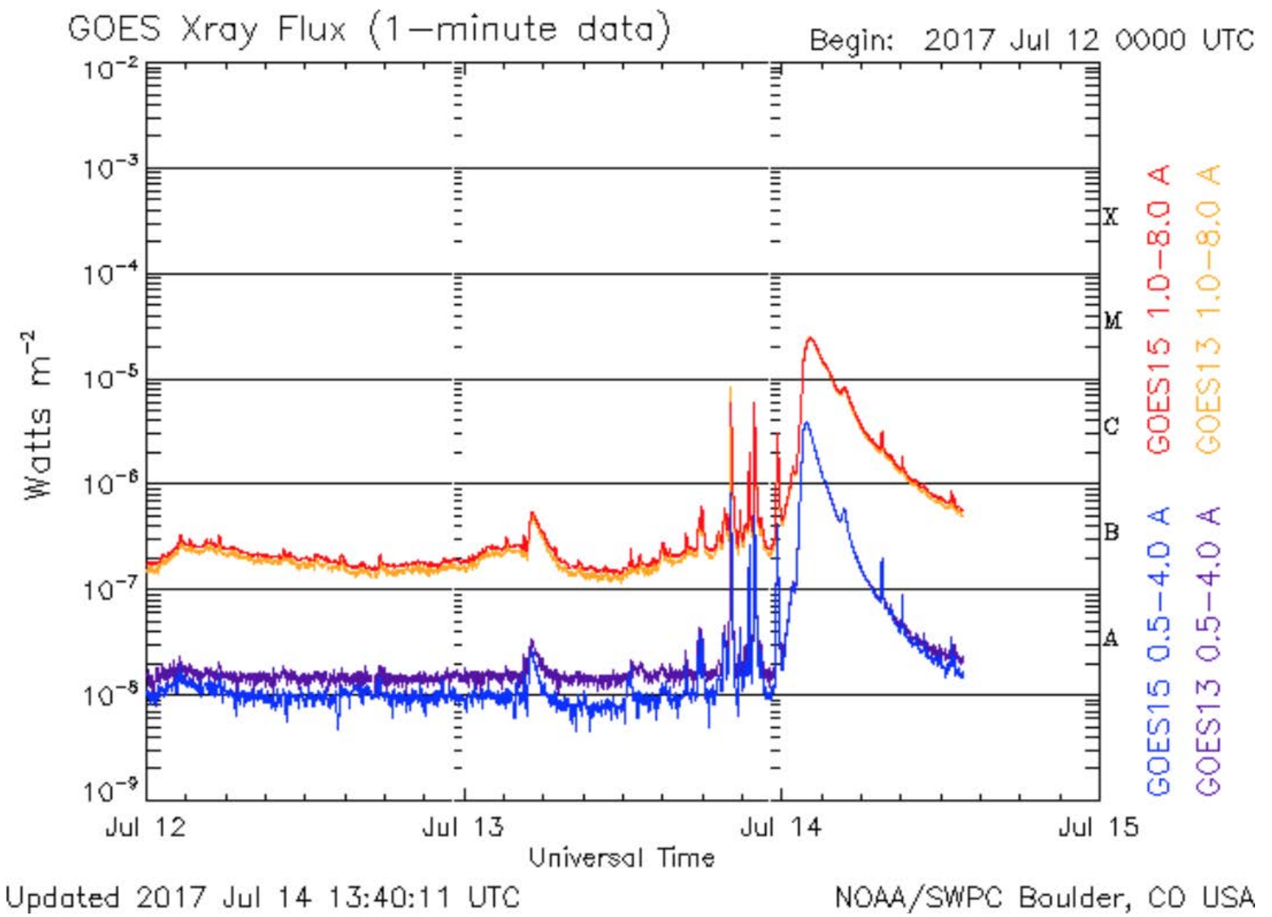
1.3 Solar Flares

The most exciting aspect of space weather is the solar flare. Solar flares are planet-sized X-ray explosions on the sun that can even produce Gamma rays during the strongest events. Notice the Earth scale on the bottom left of the image above compared to the size of the bright flare on the right. This **electromagnetic (EM)** radiation travels at the speed of light, arriving at Earth in about 8 minutes, just like the light we see with our eyes. The X-rays from solar flares can produce ionization (electrification) of Earth's upper atmosphere and ionosphere, which directly affect, and often disrupt, high-frequency radio communications.

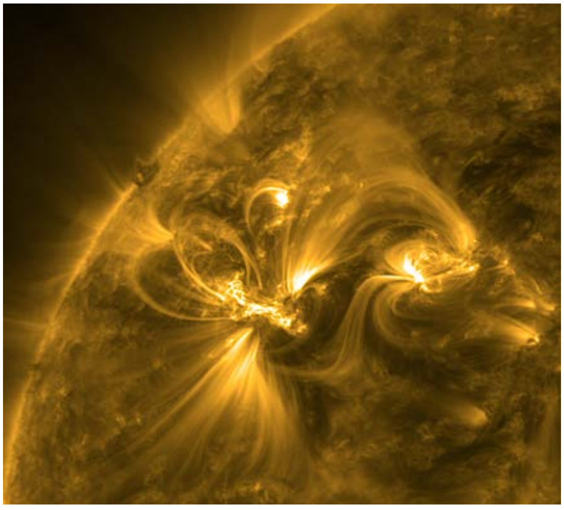
When a strong solar flare excites the upper atmosphere to the point of disrupting communications, we call it a "radio blackout". This occurs because high frequency radio communication often uses the ionosphere to bounce or "skip" a message over great distances across the globe, so the disruption of the ionosphere affects this communication ability.

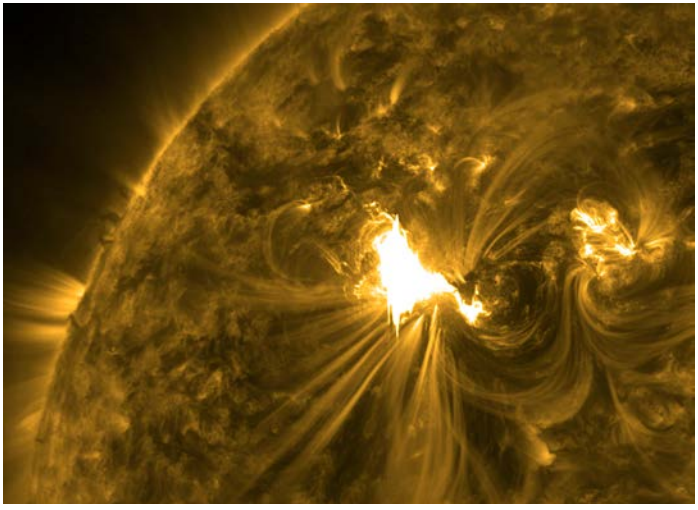
Only the sun-facing (daytime) side of the Earth is affected by the solar flare EM waves, and the blackout begins to fade the moment the solar flare ends. Solar flares can last from just a few minutes to a few hours. Short flares are called 'impulsive' flares, and longer ones are called 'long-duration' flares. Long-duration solar flares not only produce longer-lasting radio blackouts, but also have a greater chance of disrupting the solar wind with a coronal mass ejection (Section 1.5).

The next image shows a 3-day readout of X-ray flares detected by the GOES 13 and 15 satellites. We see both short-duration impulsive flares and a longer-duration flare at the end of that uptick. Notice how the impulsive events look like spikes, while the long-duration event looks like a mountain. Even this long-duration event is not as long as some, which can peak into high M and X class range (right y-axis) and stay there for half a day.



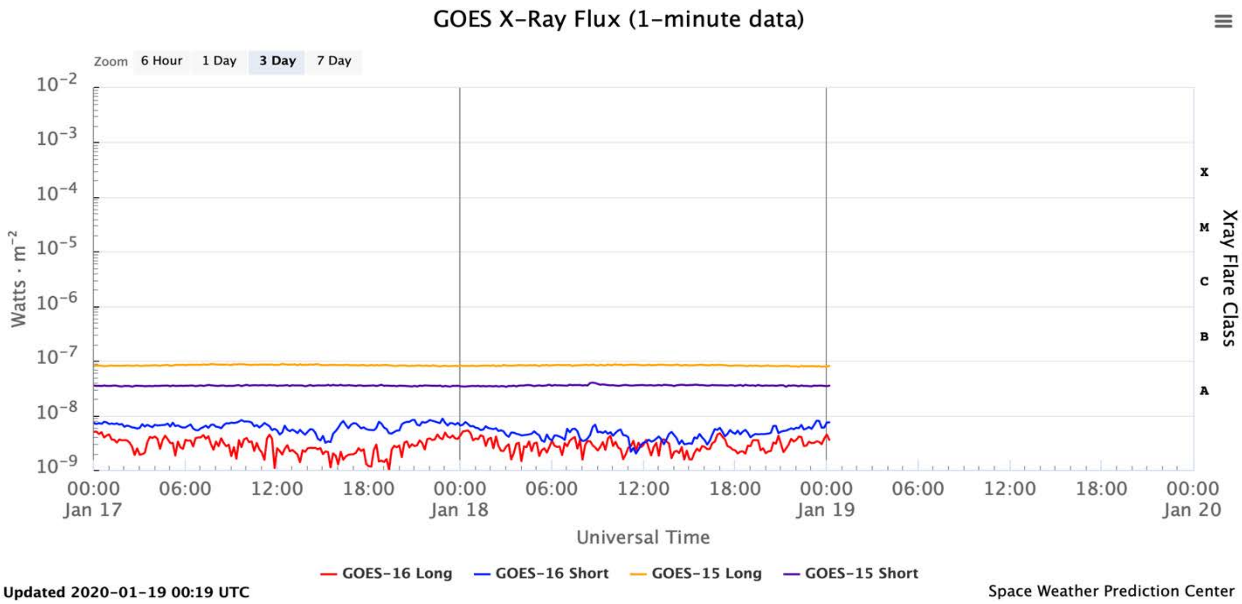
Below, we see two SDO images taken just minutes apart. On the left we see arching umbral magnetic field loops of sunspots in a complex arrangement. On the right we see a bright solar flare (white); the charged material in the magnetic fields above the sunspots destabilized, merged and accelerated particles to near-light speed. Notice the loops on the left side, missing on the right- they collided and exploded. The X-ray emission area here is larger than Jupiter.





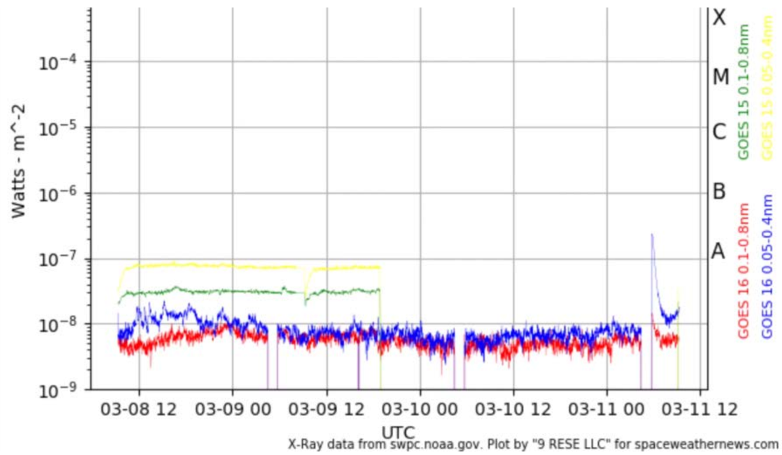
Solar flares are classified on a logarithmic scale from lowest energy to highest; the rating levels are A, B, C, M, and X.

A New Satellite, A New Chart. The next image is another GOES X-ray output, but from the GOES-16, which is the operational satellite as of 2020. There have not been many flares in its lifetime of operation, but the flares will look similar to those on the old charts, and we can still use this chart to focus on the letters running up the right-side y-axis, which show where the different flare classes can be found. We can use that scale to describe the flares we see. When describing flare level, we use the "Long" readings – seen in yellow and purple here. Regardless of any future changes to color or data stream on these X-ray charts, the Long count curves are the ones used to judge the flare class. In this case, the sun has been quiet for the few months of GOES-16 operation, and ALL curves are found within A range or lower.



Flare classes are segmented in tenths. So, while none appear on this chart above, we will have readings of X2.1, C2.7, M5.3 etc. as sunspots begin to come back in the early 2020s. You will have plenty of excitement on this chart in the coming years.

In early 2020, GOES-15 was taken out of active duty, and GOES-16 became the lone GOES monitoring unit for solar flares. In this next image we show the cessation of GOES-15 use, followed immediately by the first A class solar flare of the GOES-16 era. **Notice the 10x lower data measurements on GOES-16. Calibrations to the data may be present in future data displays.**



In general, solar flares are not going to produce significant space weather unless they are M-class or higher, except for long-duration (>2hr) C-class flares, which can also be significant. An A1 flare is 10x weaker than a B1, which is 10x weaker than a C1 . . . X1. Since X class is the highest, an X10 is 10x weaker than an X20, which is 10x weaker than an X30 . . . and so on.

We will discuss how bad things can get in more detail in a later chapter, but for now, anything in the X class range is going to be relatively exciting, and when we get to X10 things really start to rock and roll. At X20 we start to get scared, and if you see an X30 aimed this way, it is about to be a bad week on Earth.

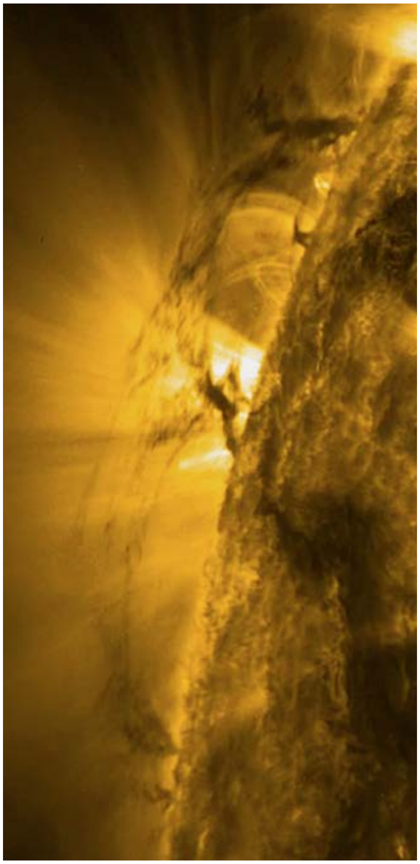
Key Points:

1) Solar flares are explosions of X-ray photons (light, wave energy) from sunspot regions.

2) Solar flare energy arrives at Earth in ~8 minutes and can trigger HF (high frequency) radio blackouts due to ionospheric electrification.

3) Solar flares are measured on a logarithmic scale, with grades from weakest flare to strongest flare of A, B, C, M, and X.

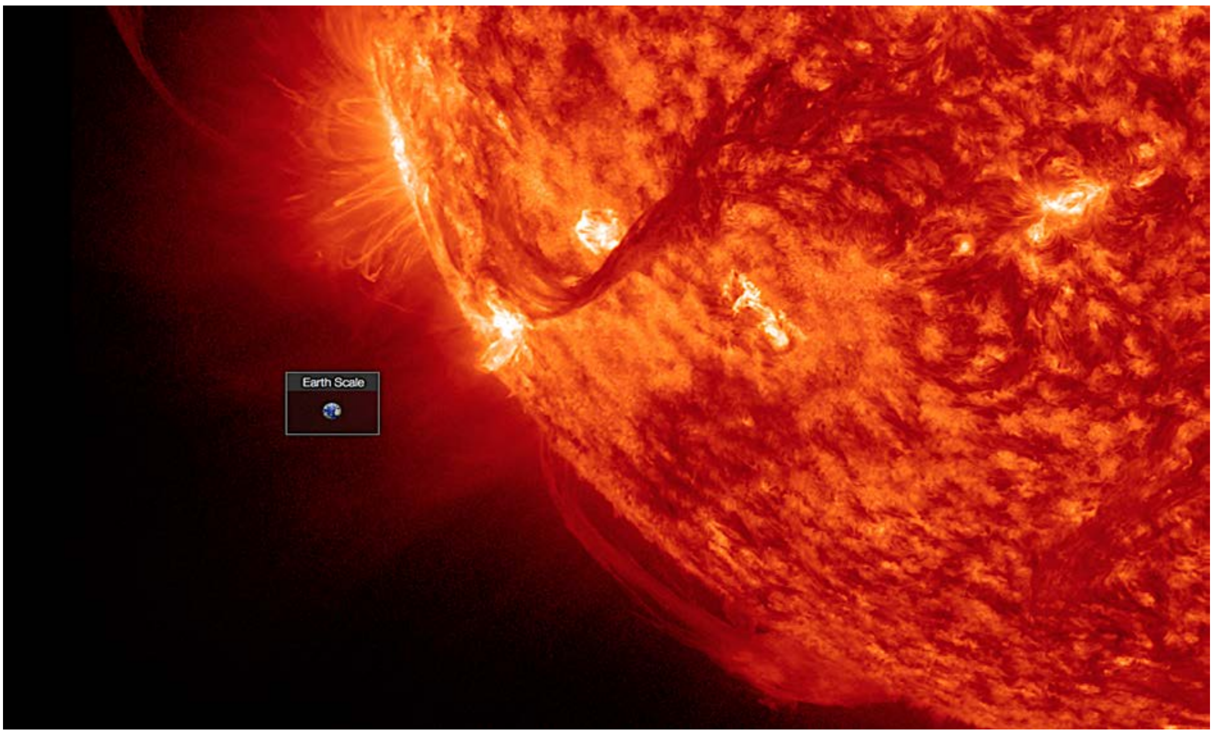
4) Strong solar flares (M class, long-duration C class flares) are capable of producing a **coronal mass ejection (CME).**

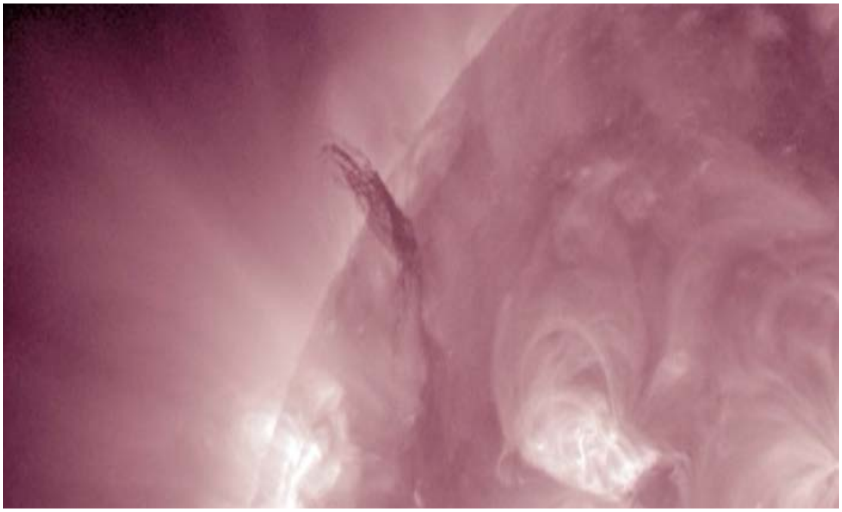


1.4 Plasma Filaments

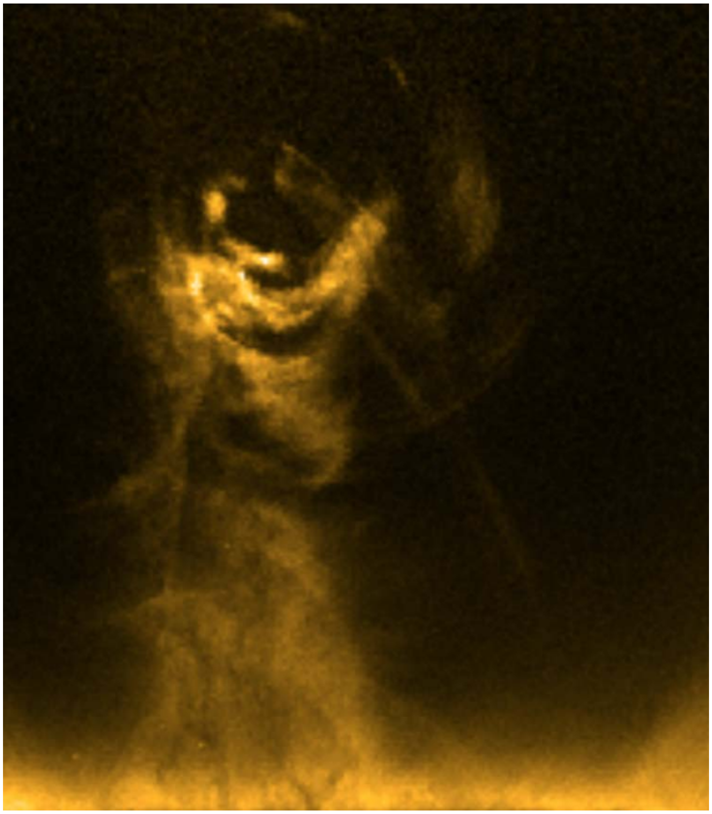
Plasma filaments, sometimes called solar prominences, are large rope-like structures of plasma hovering in the corona (the sun's atmosphere). In this SDO image we see a plasma filament as a dark silhouette arching in front of bright umbral magnetic fields. These silhouettes often give-away the presence of filaments the moment they arrive at the side (limb) of the sun.

Filaments contain all the same material that we find on the sun (hydrogen, plasma, ionized helium and ionized iron) and are governed by the same magnetic forces we see across the surface; however, they are at a much lower energy state. Filaments can contain billions of tons of plasma and can stretch out in thin lines hundreds of thousands of miles long. In the SDO image below (red), we see three plasma filaments- two are easily seen arching over the limb (horizon/outside of sun-circle) and one horizontal filament is already on the Earth-facing half. The leading filament appears as the thin, dark, continuous arc near the top-right corner of the "Earth scale" box. Many filaments are as long as 10, 20, 30 earth diameters or more.





Plasma filaments can be seen in other wavelengths as well. Seven of the nine SDO color-enhanced views offered by NASA allow us to see these filaments. In the SDO image left (pink) it appears as the dark protrusion upward from the surface near where the 10-10:30 position on a clock would be. This is 211 Ångströms, showing iron ionized to a different level than in the yellow images.

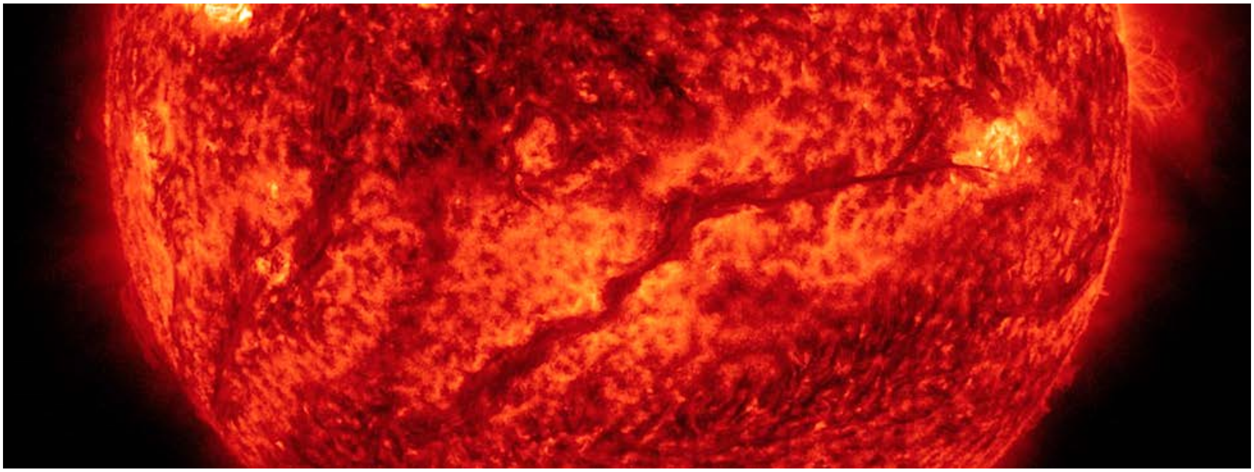


In the pink image, we can see that the size of this small filament still matches the size of the bright sunspot groups around it. On the previous page (red image) it is clear how much larger filaments can be than those sunspots, dwarfing the size of the Earth.

While plasma filaments can weigh trillions of tons, they can utterly defy the sun's tremendous attractive pull. They are suspended by electromagnetic forces that are larger in scale than the umbral fields, and they can come in any orientation, including standing straight up from the surface- like a tornado on the sun (image left).

The vortex-like appearance is no mistake; the electromagnetic forces at work on the sun often create such spiral/helical shapes.

Plasma filaments have been seen stretching nearly halfway across the sun at mid-latitude, as seen in the SDO image on the next page. The dark filament is more than 700,000 km from end to end.


A titanic filament (dark red line) graces the sun in ionized helium (SDO/AIA 304).

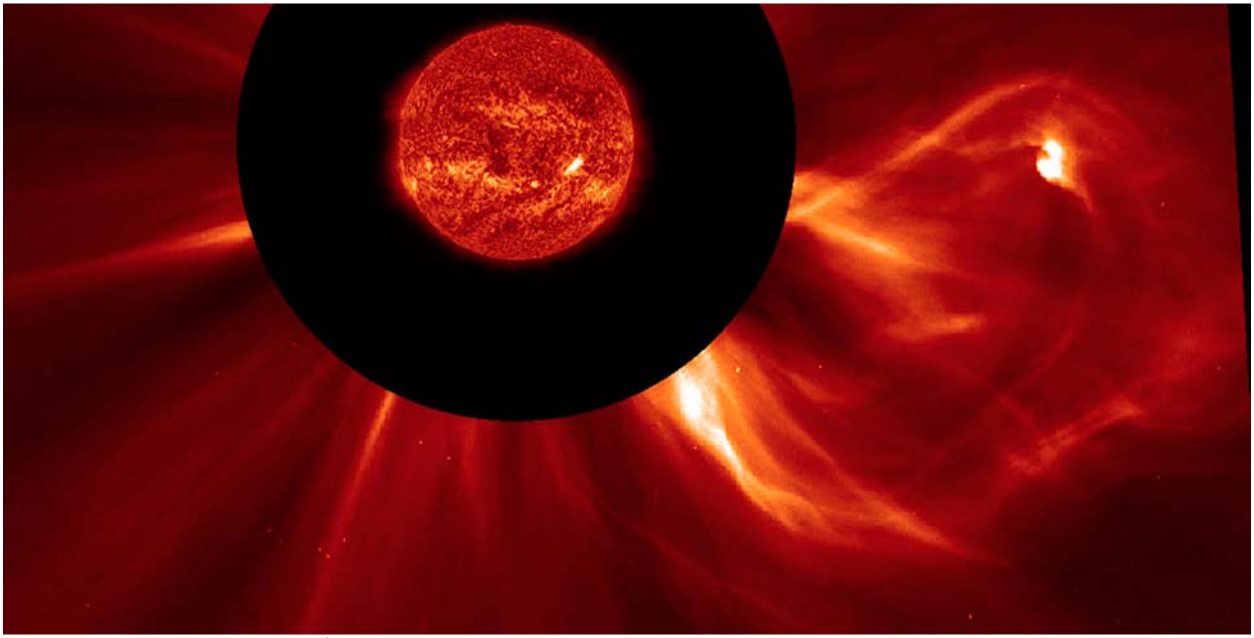
Plasma filaments, and the X-ray solar flares we learned about in the previous section, are the two solar phenomena that can trigger the release of a “coronal mass ejection.”

Key Points:

1) Plasma filaments are large rope-like structures of solar plasma that are suspended in the corona by electromagnetic forces.

2) Plasma filaments can be seen in any orientation, from flat to standing straight up.

3) Plasma filaments can release from the sun into space, producing a coronal mass ejection (CME).

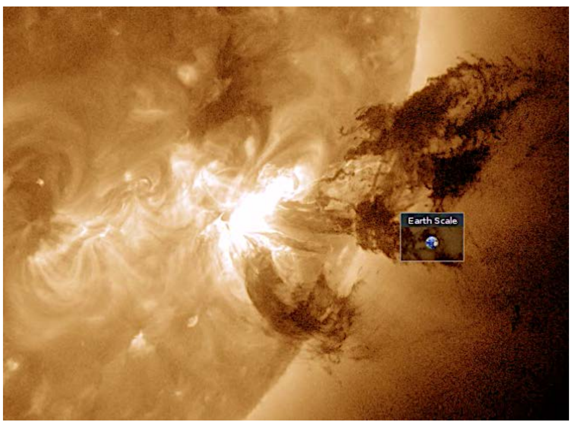


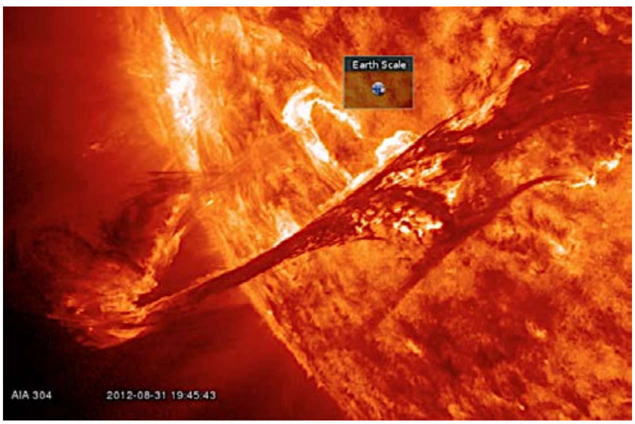
SDO image of ionized helium (middle) and the SOHO LASCO C2 coronagraph (outside) showing a CME leaving the sun

1.5 Coronal Mass Ejections (CMEs)

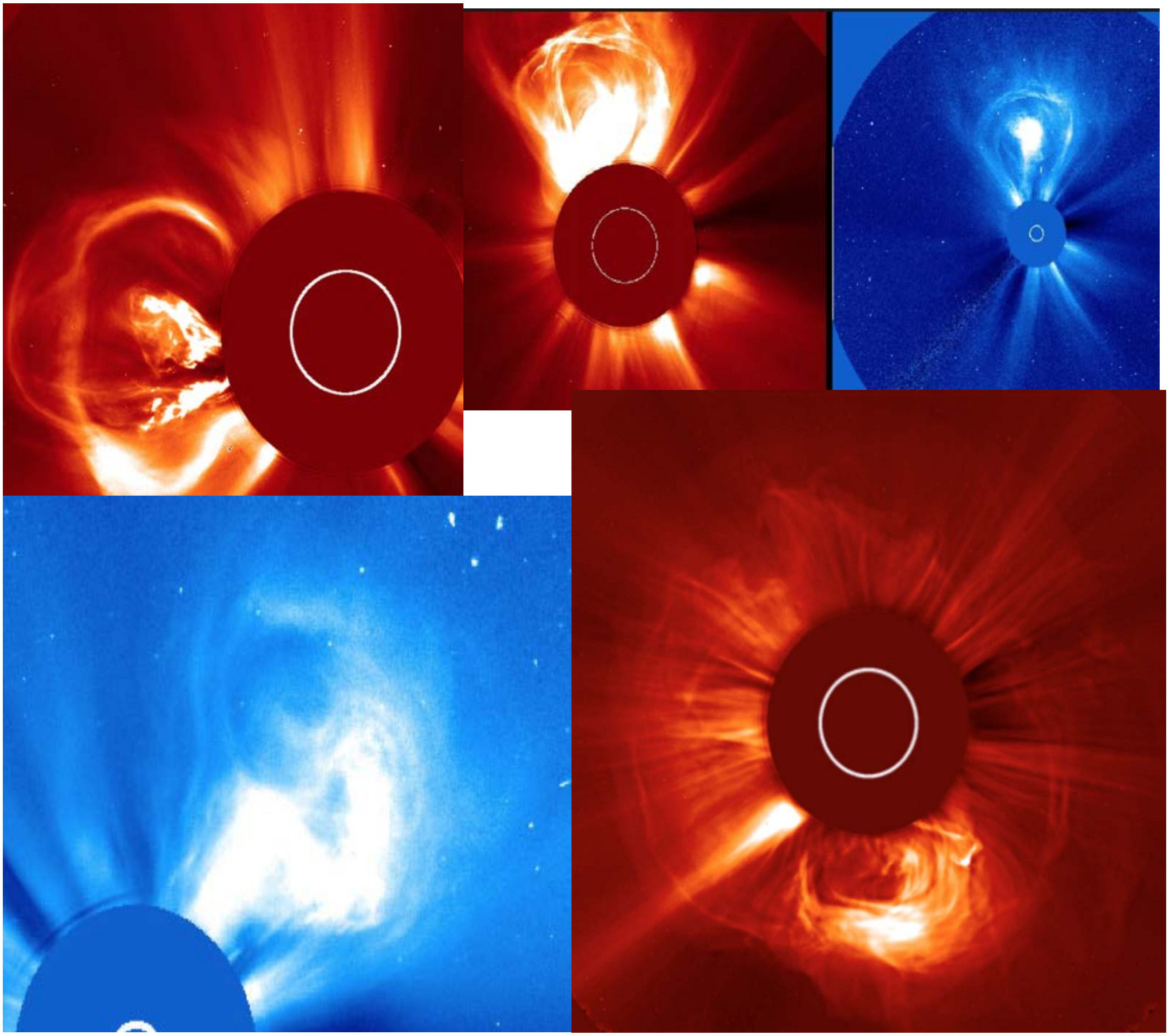
If the solar flare is the most exciting space weather event, CMEs are a close second place - the thunder to the lightning. While thunder is a sound-based shockwave caused by extreme lightning heat, a CME is an electromagnetic shockwave caused by the X-ray solar flare. CMEs are the main producer of significant space weather events on Earth. While a solar flare sends electromagnetic waves (photons) out at the speed of light, a CME is made of plasma, just like the solar wind. In the image above we see a powerful CME from a solar flare expand to exceed the size of the sun within 1 hour of exploding. Within a day, it was as wide as Mercury’s orbit; within a week it was a shockwave cloud that could fit millions of suns inside as it travelled out past Mars.

Below are two closer-in SDO images of CMEs leaving the corona. On the right, a plasma filament is ripping away from the sun (the same one we saw in the last section), and on the left, charged material is ejected from a sunspot group during a solar flare.

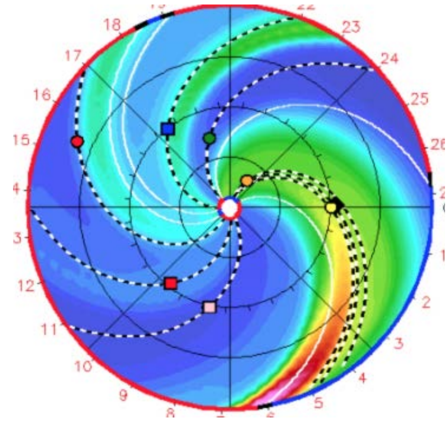


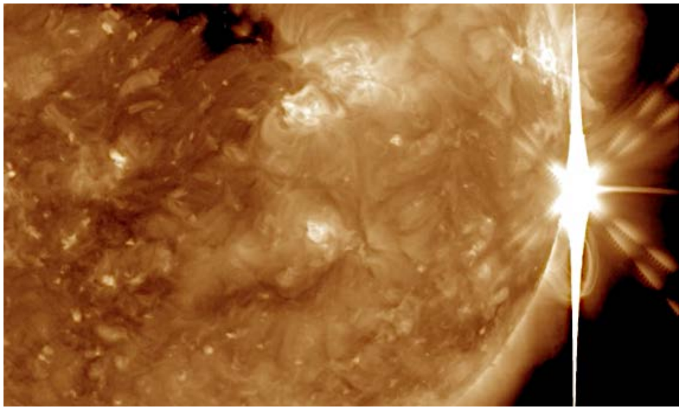


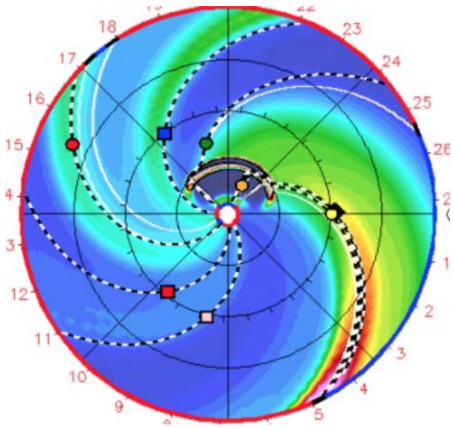
These CME shockwaves deliver waves of solar wind particles that are fast, dense and hot. Below is a collage of these CMEs from the SOHO satellite coronagraph cameras. They are ultra-sensitive to solar plasma, so an opaque disk is centered to block the sun's glare; otherwise, each image would be white. **The bottom-right image shows a CME coming towards Earth, which is called a 'halo' eruption because as it expands, it looks like a halo around the sun.** Since these cameras always look from Earth, each of the other images show CMEs that will miss our planet (they are going off to one side).

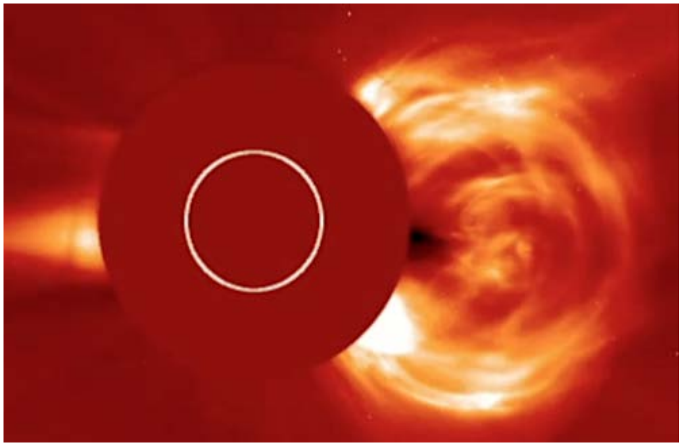


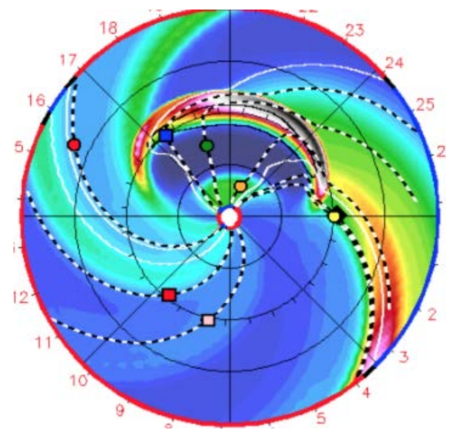
Consider the size of these eruptions: the sun is a tiny dot behind the central inner circle, so these images taken within hours of a solar flare or filament eruption, show CME clouds already big enough to hold dozens to hundreds of suns. On the next page is a sequence of a flare and CME as viewed by the SDO/SOHO satellites, and how it was tracked with the ENLIL spiral.

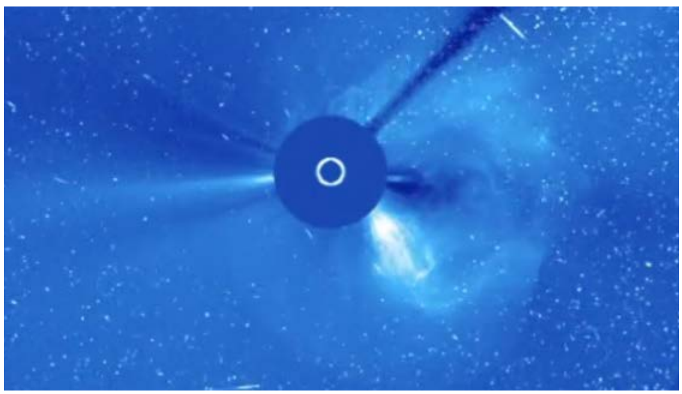












The sequence, top to bottom, starts with a solar flare (SDO image, top right) with nothing to see on the ENLIL spiral. Down the page we move to the close-in coronagraph (SOHO C2, red) and farther field (SOHO C3, blue) to see the expanding CME arc. On the ENLIL spirals we can see how that data is presented to us from a northern view looking down on the solar system. The arc travelling ‘up’ on the ENLIL spirals as you look down the page is the CME. Can you see how ENLIL spiral shows the CME missing Earth (yellow dot)? This confirms what we notice as the flare occurred on the limb (side) of the sun and the CME cloud went out to only one side.

When a CME *does* hit Earth's magnetosphere there is a **simultaneous change** in the profile of the solar wind across nearly all metrics. Using the timestamps across the bottom of the image below, find the 23:00 hour near the middle of the plot, the hash-mark to the left of 00:00. This is the same type of solar wind data as before, except from the ACE satellite. The bottom three panels all increase at the same time, along with the top panel, and what had been a calm trend in the blue Phi angle took a hit to lower degree angles at the time the other panels showed the change. The key item in identifying a CME impact is the simultaneous change in telemetry. **CMEs are one of the primary causes of geomagnetic storms at Earth (Section 1.8).**

Key Points:

1) When a solar flare occurs or a plasma filament ‘erupts,’ there can be a large explosion of charged particles outward into space, called a coronal mass ejection (CME).

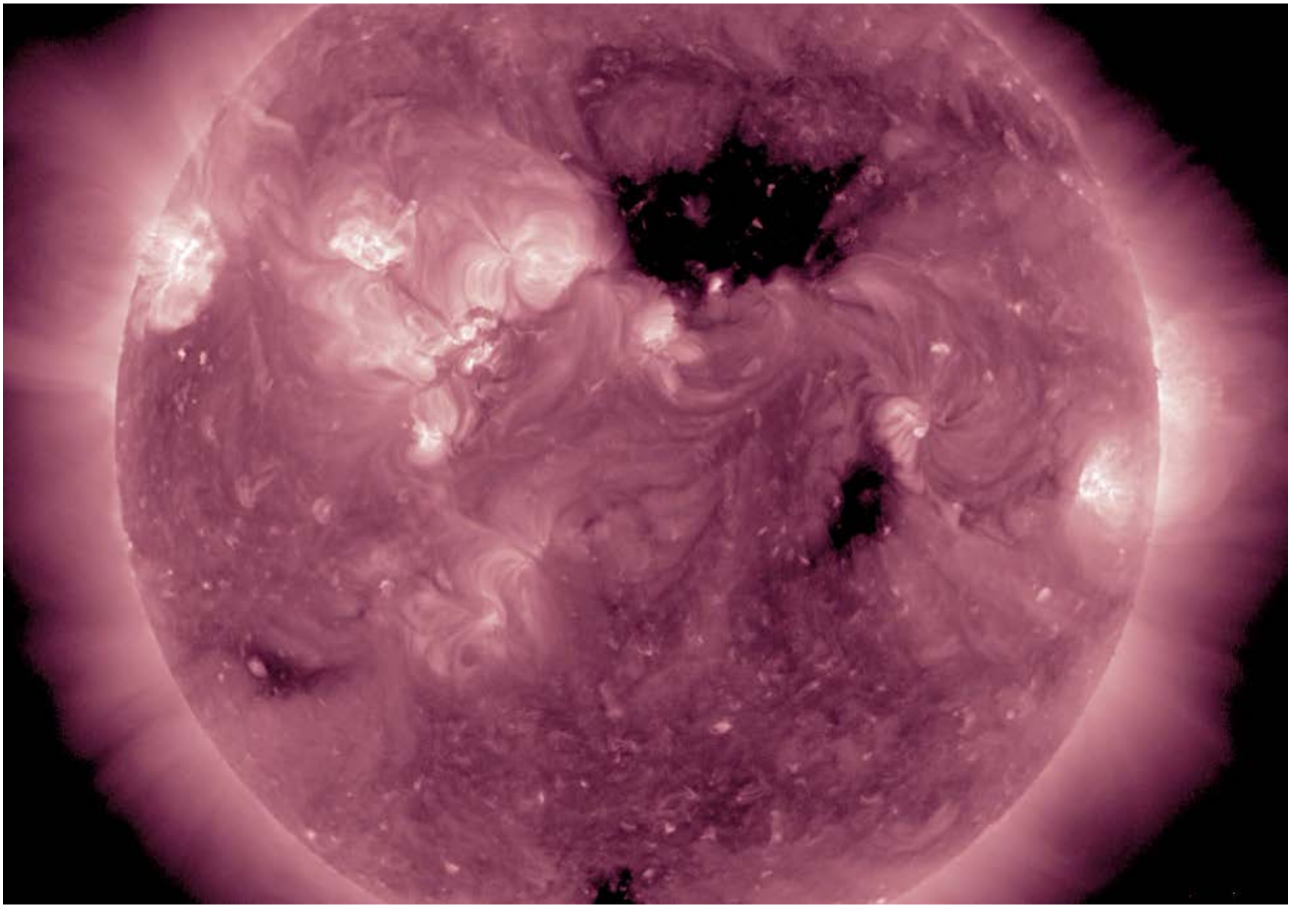
2) CMEs are made of the same material as the solar wind, but at higher energy, and often at MUCH greater densities, speeds, and temperatures.

3) Like solar flares and plasma filaments, CMEs can be seen on SDO imagery, but also on coronagraphs as the shockwave expands and travels through the solar system.

4) On SOHO images, halo eruptions indicate that Earth is in the line of fire, while seeing the cloud expand out to one side indicates it will miss Earth.

5) CMEs impacting Earth will show up in the solar wind as **simultaneous changes** in the different telemetry points.

6) CMEs are one of the primary causes of “geomagnetic storms”.



1.6 Coronal Holes

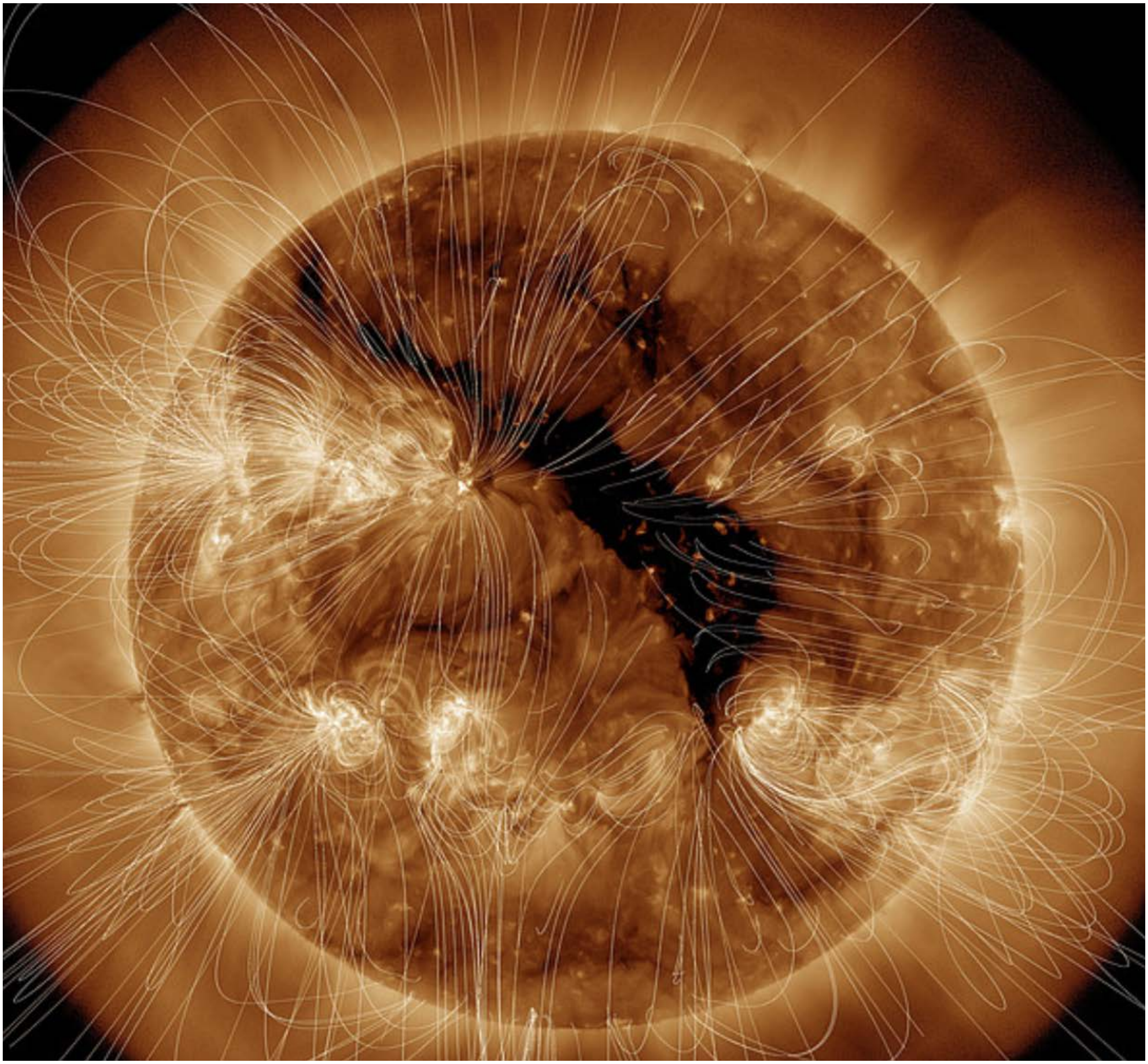
If you can see the black areas just right and up from center in the solar image here (and the smaller ones near the bottom and left side), congratulations, you can locate coronal holes! These are areas in the corona that are nearly devoid of charged particles and plasma. <u>Corona = Solar Atmosphere; Coronal Hole = Hole in the Sun's Atmosphere.</u> This image is from SDO in 211 Ångströms (wavelength) of light, which is especially good for spotting these coronal holes.

Coronal holes are nearly-empty areas that extend from near the solar surface up into outer space. Plasma filaments can also appear dark, but they are thin and often visible separate from (above) the solar surface. Unlike the thinner filaments, coronal holes are usually larger patches like you see here, not at all thin, and easily contrast with the bright white umbral magnetic fields above sunspots.

Why are these regions empty? Because of the solar system's interplanetary magnetic field (IMF), which we learned about earlier in this chapter. The IMF takes all the charged material in those areas of the corona out with them, leaving the area vastly less populated with plasma than the surrounding regions. These are the same IMF connecting planets to the sun through the solar wind electric field of plasma. Umbral field loops, and the larger coronal magnetic fields seen in the next SDO image,

not only contain particles in their loops, but they create a magnetic shell that traps escaping solar wind.

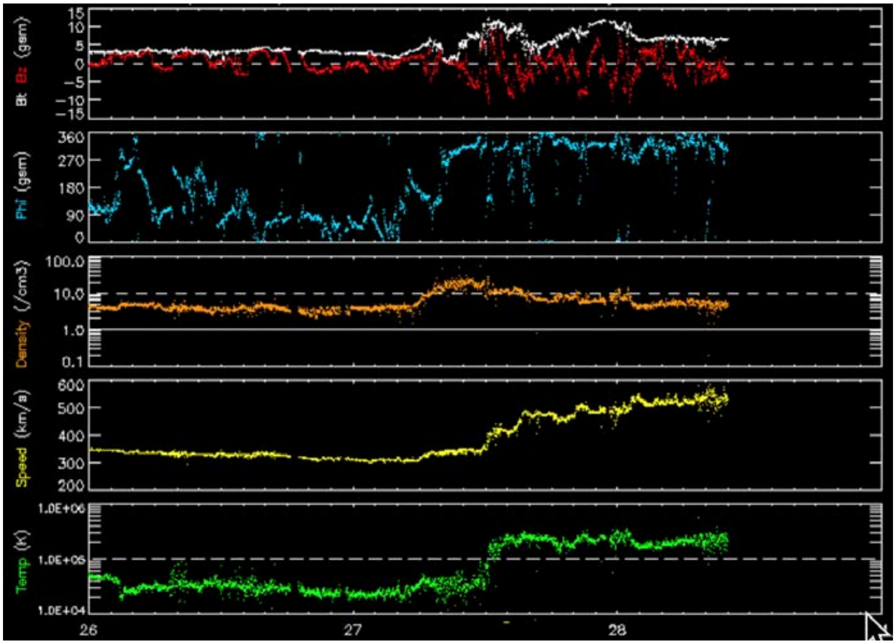
In the SDO image below we see the magnetic fields associated with the sun. Notice how the umbral magnetic fields of sunspots are looped and confined to the sunspots groups, while the fields associated with the large coronal hole are straight lines outward into space. Those larger white fields arching over larger areas are the coronal fields we mentioned in the previous paragraph.



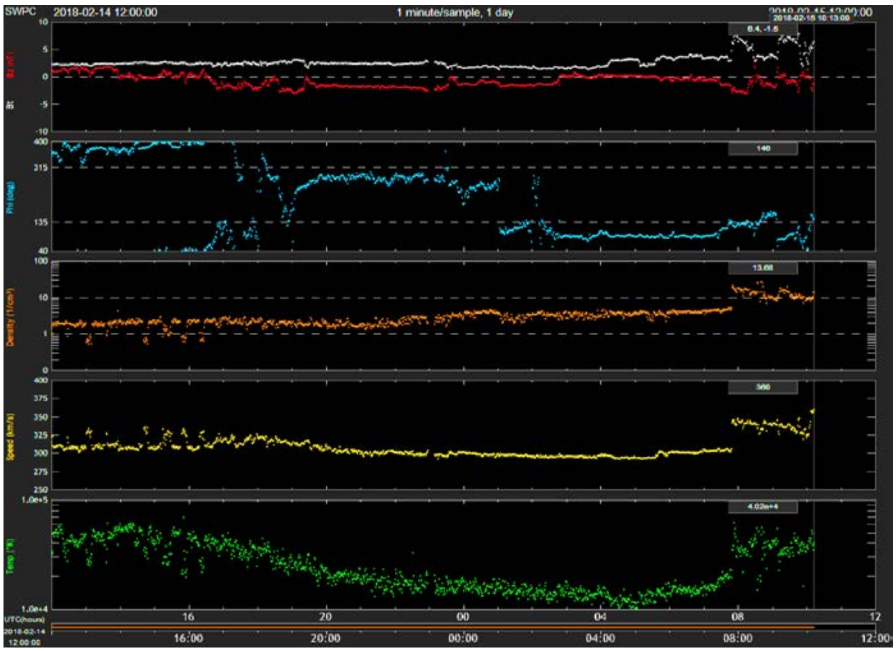
The practical effect of the “open” fields of coronal holes is extra force for the solar wind, coupled with less magnetic restriction on those electric particles. This is why coronal holes often emit intensified solar wind. The solar wind streams from coronal holes themselves are not tremendously dense, just very fast and hot, but they catch up to slower-moving solar wind out ahead of them, bunching up those slower particles like snow on the blade of a shovel. This creates a density

shockwave at the leading edge of the fast coronal hole stream that acts very much like a CME. Because of this shockwave, coronal hole streams can also produce geomagnetic storms.

In the top image, we see a coronal hole stream impact in the solar wind. The plasma density of the solar wind (orange) has a sharp increase on the 27th, lasts for a few hours, and then begins to descend. It begins to descend before the speed (yellow) and plasma temperature (green) begin to rise, and density continues to drop as the speed and temperature continue to rise/remain higher. The rise in speed and temperature represents the arrival of the fast, sparse solar wind stream, and the density peak before it represents that "snow on the shovel blade" - the slower particles bunched up ahead of the faster coronal hole stream.



Contrast this with a CME impact (bottom image), where changes in the solar wind telemetry are simultaneous; coronal holes deliver the density shockwave first (along with the phi angle change in blue) and then the fast/hot coronal hole stream onset begins.



Coronal Hole or CME? It Is About Timing the Density & Speed Effects:

If the density wave precedes the speed/temperature rise, it is a coronal hole.
If the solar wind changes all at once, it is a coronal mass ejection (CME).

While this distinction is a critical aspect of analyzing space weather, both CMEs and coronal hole can cause geomagnetic storms.

Key Points:

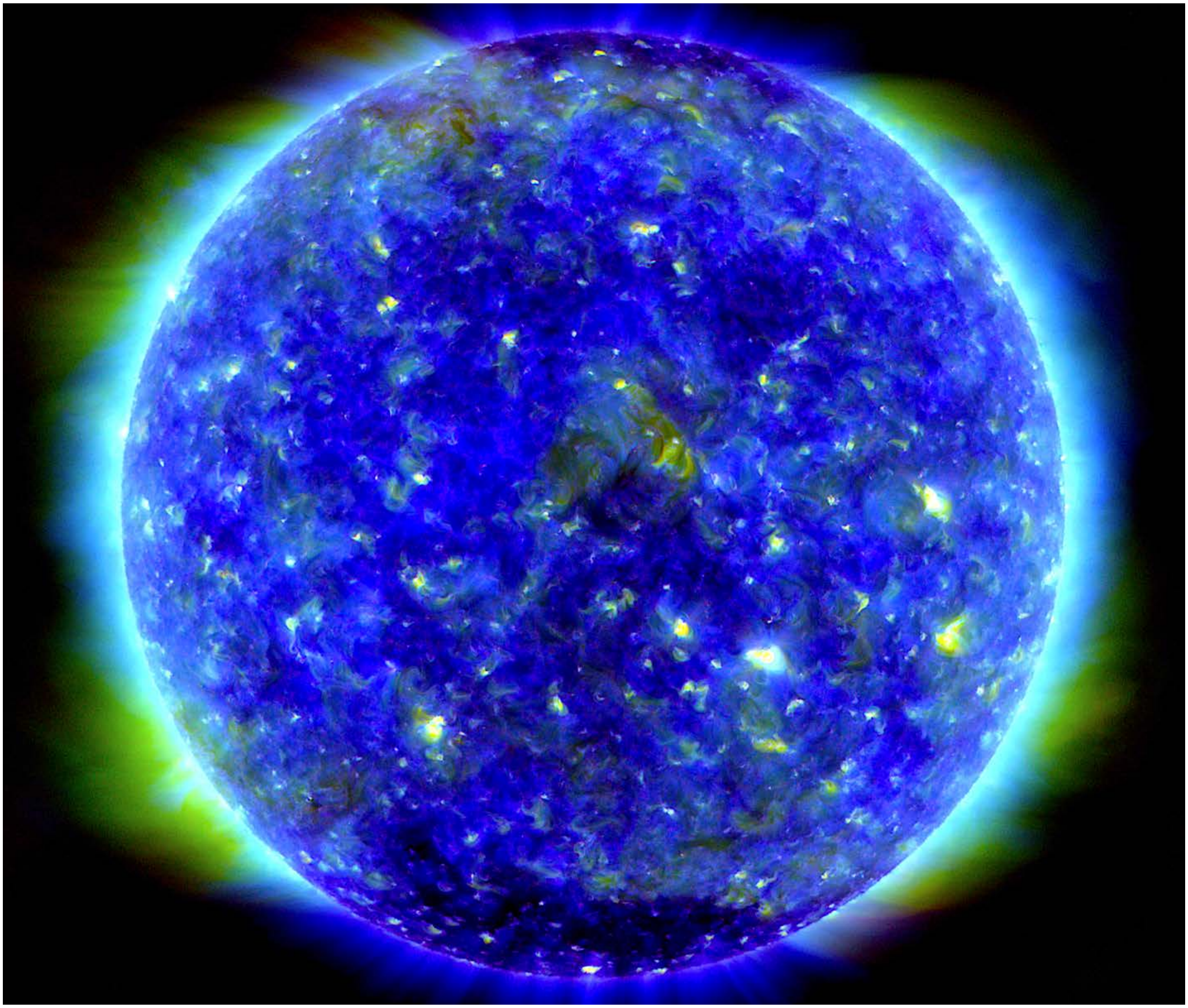
1) Coronal holes are regions where the sun's magnetic fields do not immediately loop back down to the sun, but instead stream out into space (as shown in Section 1.1).

2) Coronal holes emit stronger, faster and hotter solar wind that can catch up to the slower solar wind ahead of it, creating a density shockwave ahead of the fast stream.

3) Unlike CME impacts on the magnetosphere, which present simultaneous changes in solar wind telemetry, a coronal hole signature has the density shockwave arriving first, at the speed of the current stream. Afterwards, the faster and hotter particles arrive while the density profile is reduced dramatically.

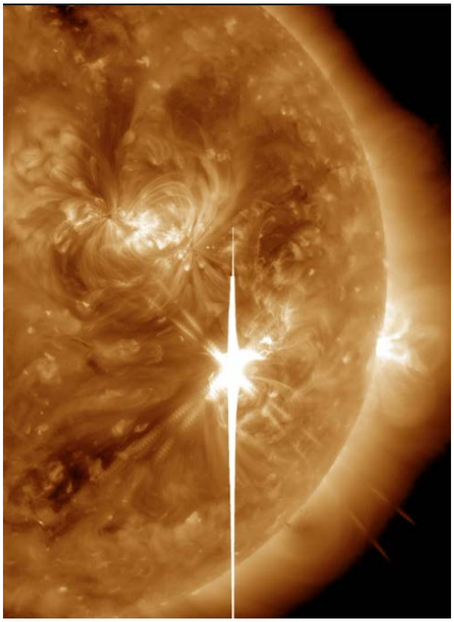
4) Since coronal hole solar wind streams act much like CMEs, they are one of the causes of "geomagnetic storms".

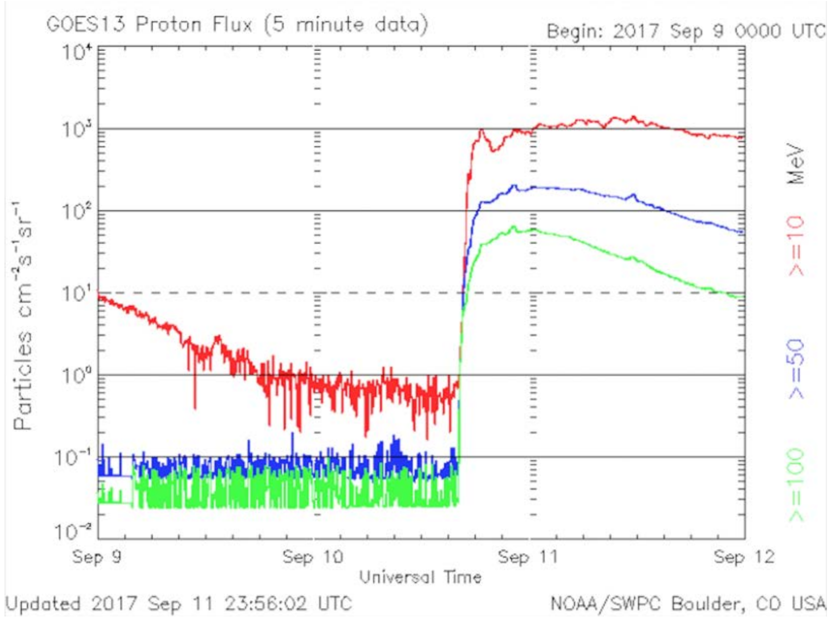
5) While umbral magnetic fields contain plasma near the corona, the IMF from coronal holes forces the plasma away from the corona.



Did you know that you can find real-time solar images like this one any time you want?

Just go to https://sdo.gsfc.nasa.gov/data/ !





1.7 Solar Energetic Particle (SEP) Events

We have mentioned that solar flares, plasma filaments, their CMEs, and coronal hole streams can intensify the solar wind and cause a “geomagnetic storm”, but there is often a critical step in between. Strong solar flares can hit Earth with particles long before its CME arrives; this is called an SEP event. The images above show a solar flare on the left, from SDO, and an SEP event (a proton radiation storm) on the right, which occurred minutes later. We can see that energetic protons of different energies surged from their low levels around 1 proton every 1-2 cm^3 up to 10-1000 protons per cm^3 - an average increase of 1000x across all three tracked proton energy levels.

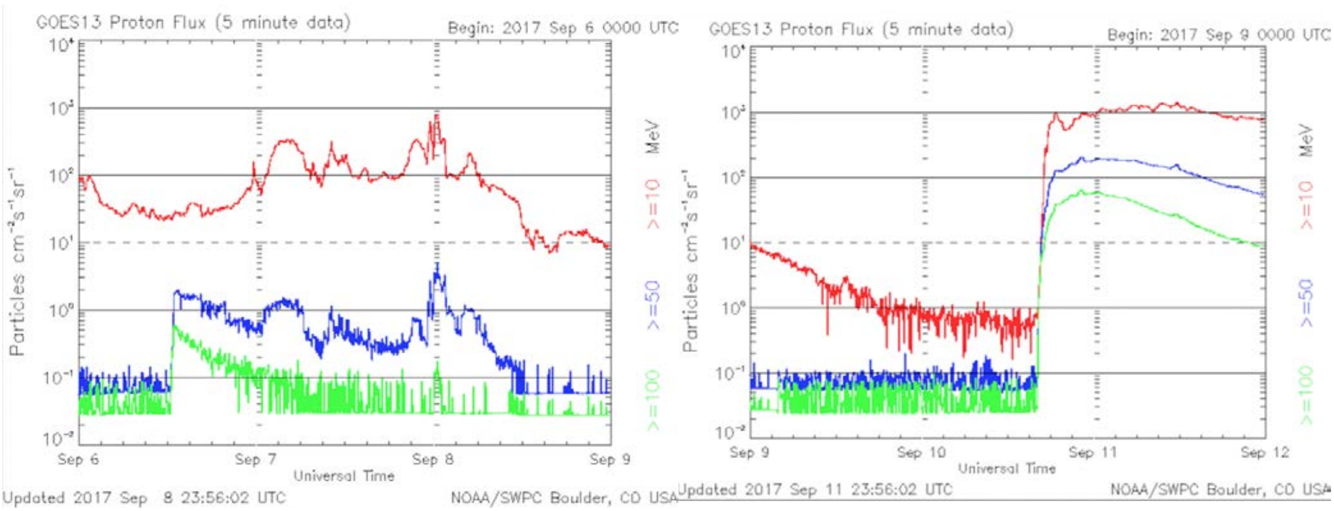
Section 1.1 briefly discussed the interplanetary magnetic field (IMF) that connect the planets back to the sun, and we learned that every 8 minutes, a flux transfer event sends charged particles directly along this IMF, which bypasses Earth’s magnetosphere, and pours solar plasma into the upper atmosphere. Sometimes, the surge of particles to Earth is extreme. This occurs following a large solar flare and CME that hits Earth’s magnetic connection to the sun (IMF), driving a different kind of particle explosion through space.

When a powerful flare/CME hits Earth’s IMF connection to the sun, it helps fuel extreme surges of these charged particles - an extreme flux transfer event that can last for hours to days. While CMEs take a few days to arrive in most cases, the highly-energetic SEP arrive within minutes of the solar flare. While we can see solar flares in SDO’s view of ultraviolet light, and can see CMEs via SOHO’s coronagraphs, there is no way to see the energetic particles from the sun traveling along the IMF to Earth.

During these SEP events, either protons or electrons streaming towards Earth undergo a large spike in particle counts. This influx of charged material occurs near the polar regions, spreading to lower latitudes only in the most extreme circumstances. Our main protection from these events is the atmosphere because SEP events often bypass Earth’s magnetic field along the IMF. Luckily, the

atmosphere does a very good job protecting those on the ground. Astronauts and passengers on high-latitude flights are most at risk from radiation due to SEP events, which is why space stations have shielded safe rooms, and airlines will reroute polar flights during major solar flares.

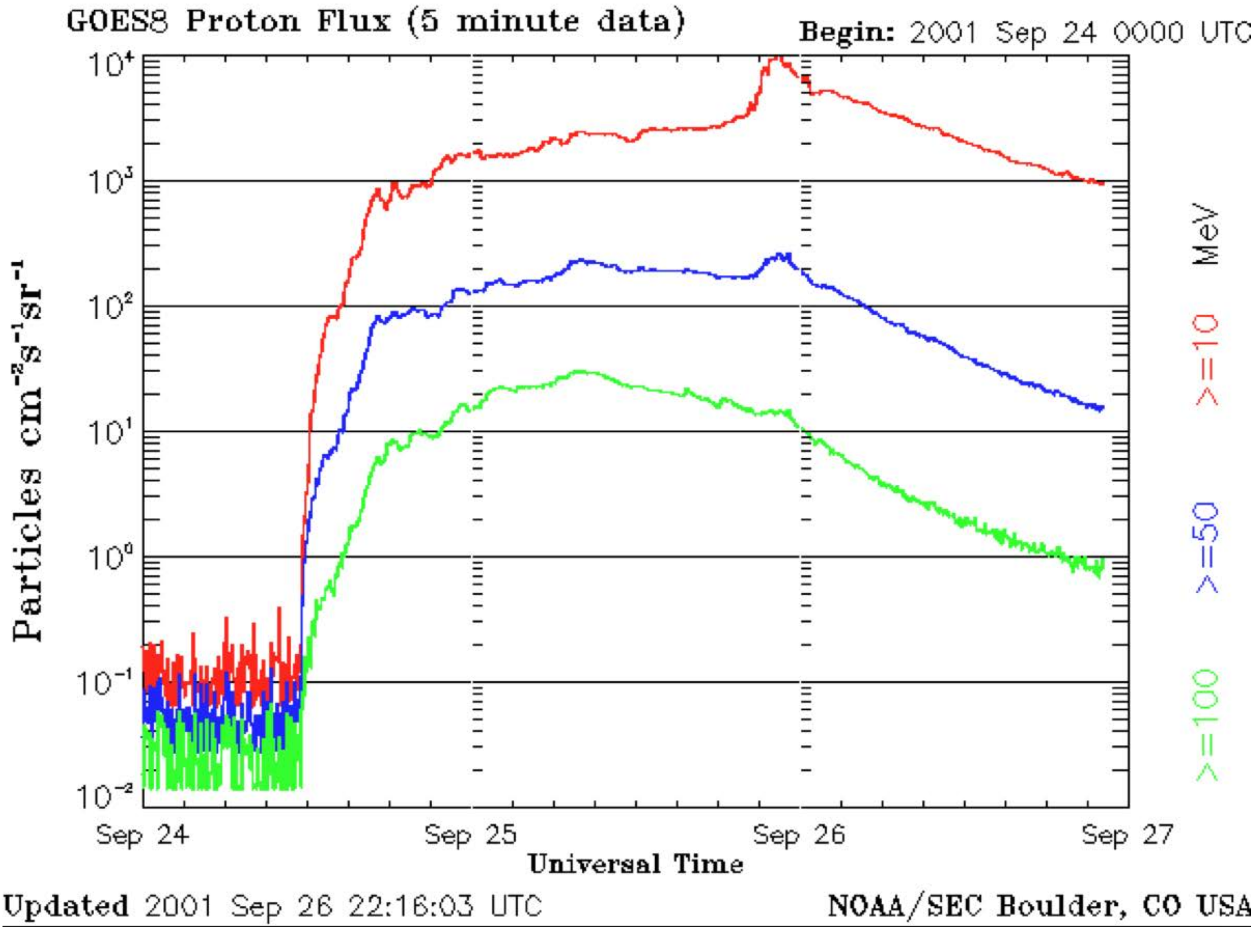
When viewing an SEP event, one can often tell if there is more coming or if the worst is already underway. Compare the two images of SEP proton storms below:



On the left, we see enhanced proton counts that follow no real shape or pattern; these are probably always going to signify that the worst has arrived unless more solar flares occur, and indeed all of the upward enhancements on the left are due to additional solar flare eruptions, including one that happened at exactly 00:00 UTC on September 8th. It was a flurry of activity that produced seven distinct SEP events over almost three days.

By contrast, on the right side we see a very well-defined shape; there is a sharp rise upward followed by a flat top and much less variation. In this event, there was just one solar flare. **When we see that “UP and FLAT” profile, we have hit the proton “stream limit”.** Powerful flares and CMEs are what drive large/fast spikes in proton bombardment, however those CME shockwaves are highly electromagnetic themselves, and if strong enough, can hold back further increases in the SEP stream density due to their own magnetism (creating the flat top). This means that when you hit the stream limit, an even stronger “punch” of protons is waiting to arrive with the CME. This second punch does not always occur when you hit the stream limit, as was the case in the period depicted in the right-side image, when the CME carrying the extra punch did not hit Earth, taking the extra protons out with it.

On the next page we have an example where a powerful solar flare and CME caused an SEP proton radiation storm that hit the “stream limit” AND Earth received the secondary punch of protons that occurred when (and only because) the CME did in fact impact Earth.



In the image above, the solar flare and CME occurred on September 24th. The stream limit was reached that night and continued on the 25th. The CME arrived at Earth late on the 25th, producing the second spike in protons to ~5x the density flow of the stream limit reached by the >10 MeV (red) protons, and ~75 to 100 % higher bombardment in the >50 MeV (blue) protons.

To illustrate how large of a "punch" this is: the >10 MeV protons (red) began at less than 1 proton/cm^3 on the 24th and surged to a stream limit of ~2000 protons/cm^3 that night. However, the secondary punch delivered by the CME impact reached nearly 10,000 protons/cm^3. **That bump up top might look small**, but it's actually 5x greater a spike than the initial rise on the 24th, which appears bigger to the eye due to the logarithmic scaling of the chart. This is a rare example of a 10,000x particle increase event. The initial rise in the >50 MeV (blue) protons was from 1 to ~100 protons/cm^3, while the "punch" took levels to nearly 200 protons/cm^3- again, the bump only *looks* small.

The CME impact is where the big show begins on Earth, and that second SEP wave, the "punch", and the radiation storms they deliver, are only part of the story. The main effect of space weather events (solar flares/CMEs, filament eruptions, coronal holes) acts on the Earth's magnetosphere, and if that effect is great enough a geomagnetic storm occurs.

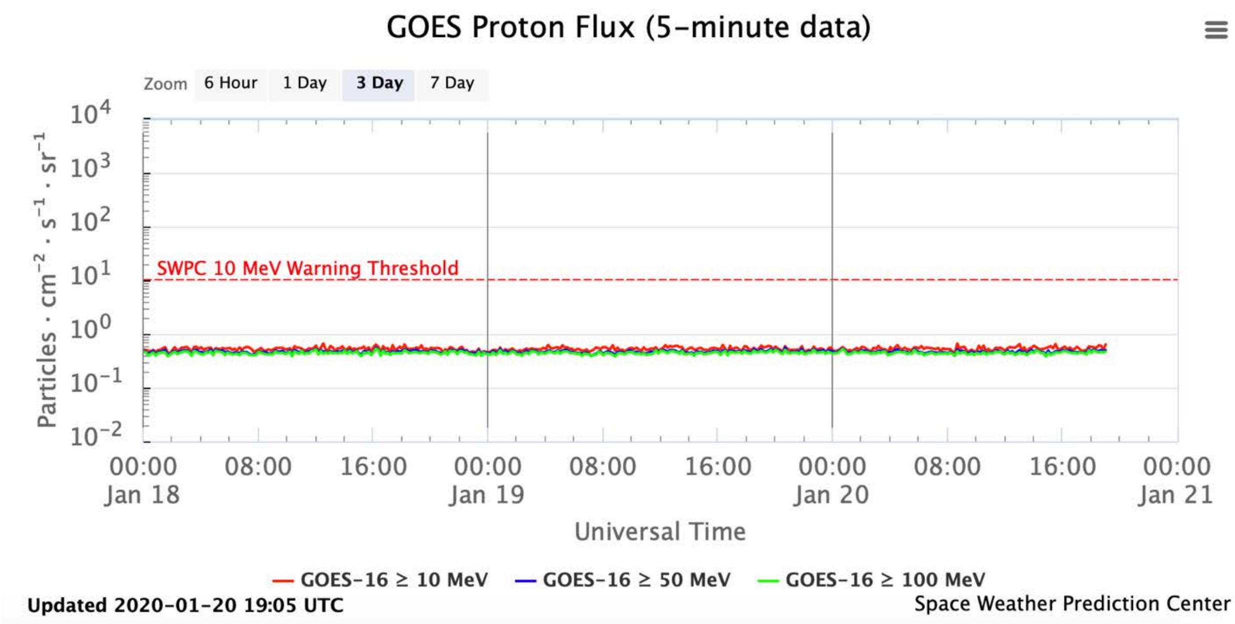
Key Points:

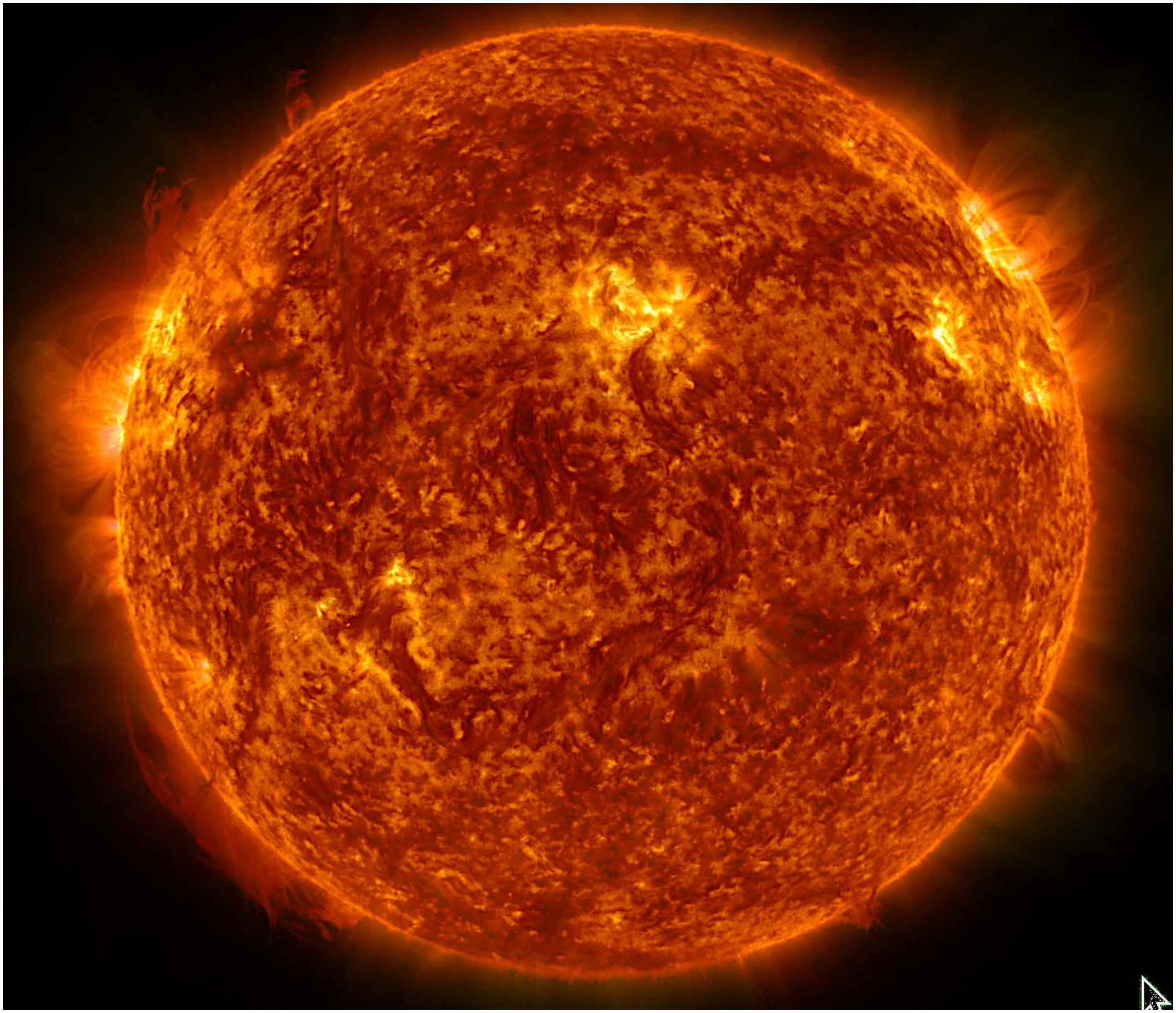
1) Solar flare energy can accelerate high-energy particles along the IMF and cause excess radiation to impact Earth (SEP event), posing a risk to the ISS and some airline flights.

2) Reaching a flat-top "stream limit" after a rapid rise in proton flux (usually after a solar flare), indicates the CME carries the bulk of the proton radiation.

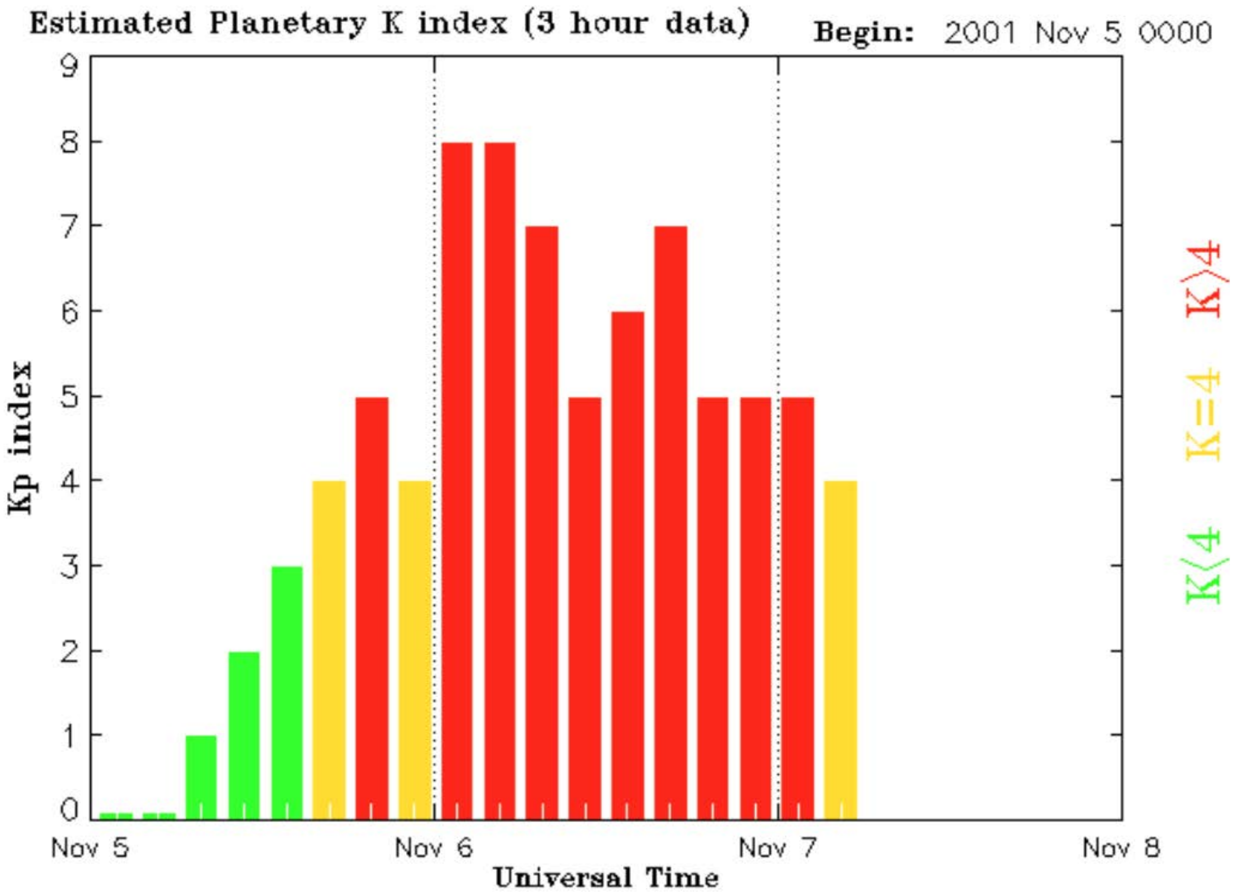
3) The CME delivers that last "punch" to the proton levels only if it impacts Earth, and these can represent increases in particle counts that can be much greater than the initial onset rise of the storm.

*This is what the latest SEP charts from the NOAA Space Weather Prediction Center look like. As with solar flaring, there have been no major events as of their latest updates in 2020, but this chart will become exciting in the years ahead when solar flares occur.





NASA.gov SDO/AIA 171 & 304



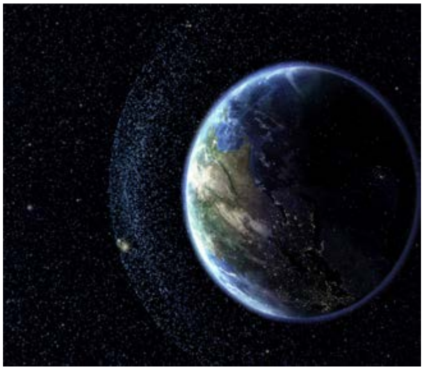
1.8 Geomagnetic Storms

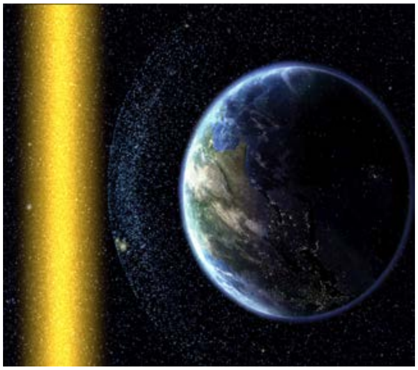
Geomagnetic storms are the bread-and-butter of Earth-focused space weather. Solar flare energy can ionize the atmosphere, and solar energetic particles (SEP) can deliver solar plasma directly into the upper atmosphere, but neither is as powerful in influencing all layers and planetary systems as the geomagnetic storm. The image above is of the “Kp index”, which measures the total disruption to Earth’s magnetosphere. On the scale, 0-3 (green) presents relatively calm conditions, 4 (yellow) indicates instability of the magnetosphere, and 5-9 (red) indicates geomagnetic storm conditions.

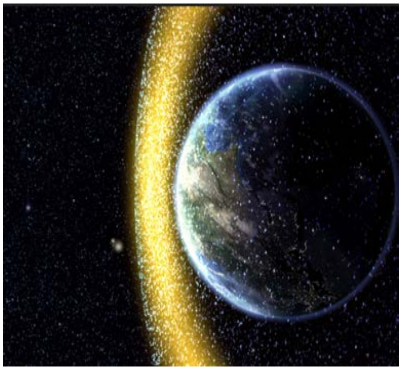
Within even one of the color groups there exists a great deal of variation. It takes utter silence to have a Kp of 0, while there is usually slightly-above average solar wind intensity during Kp3 events. A Kp5 geomagnetic storm is likely to produce beautiful auroral displays near the poles, but the scarier effects are reserved for Kp8+ storms, which can be 100 to 1000 times more powerful.

CMEs and coronal hole streams present sharp changes in the electric environment of near-Earth space. When a CME or coronal hole stream strikes our planet, the magnetosphere is compressed, driving two key processes that end up affecting our weather and climate, as well as earthquakes, our technology and health.

The compression of Earth's magnetic field can be seen in the next set of images. The sequence portrays a CME shockwave (yellow) hitting Earth's magnetic field and being directed around our planet, while partially interacting (coupling) with the magnetosphere to deliver its energy to the Earth system.

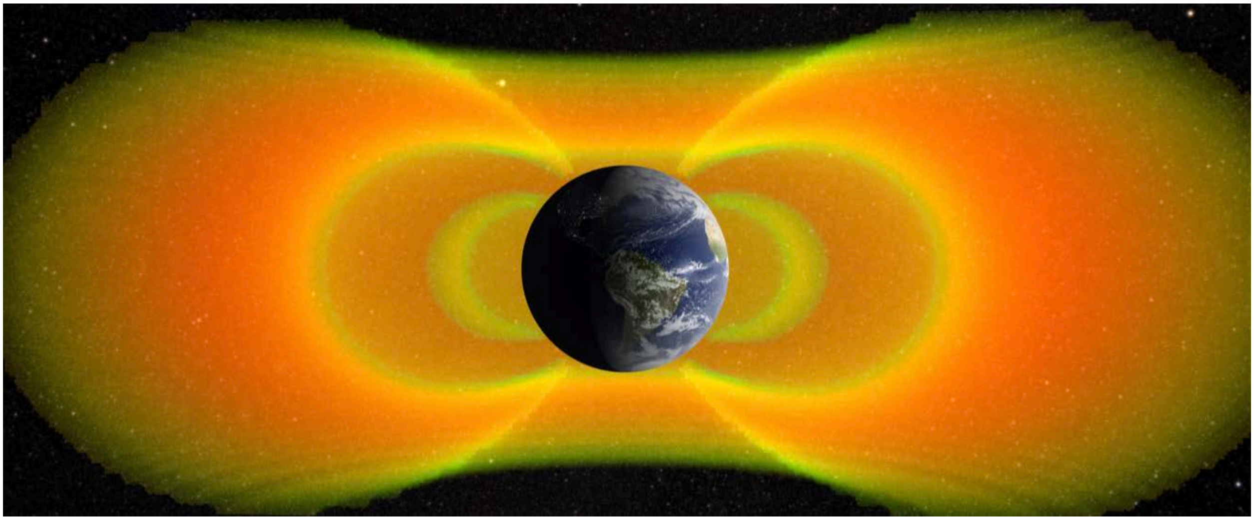


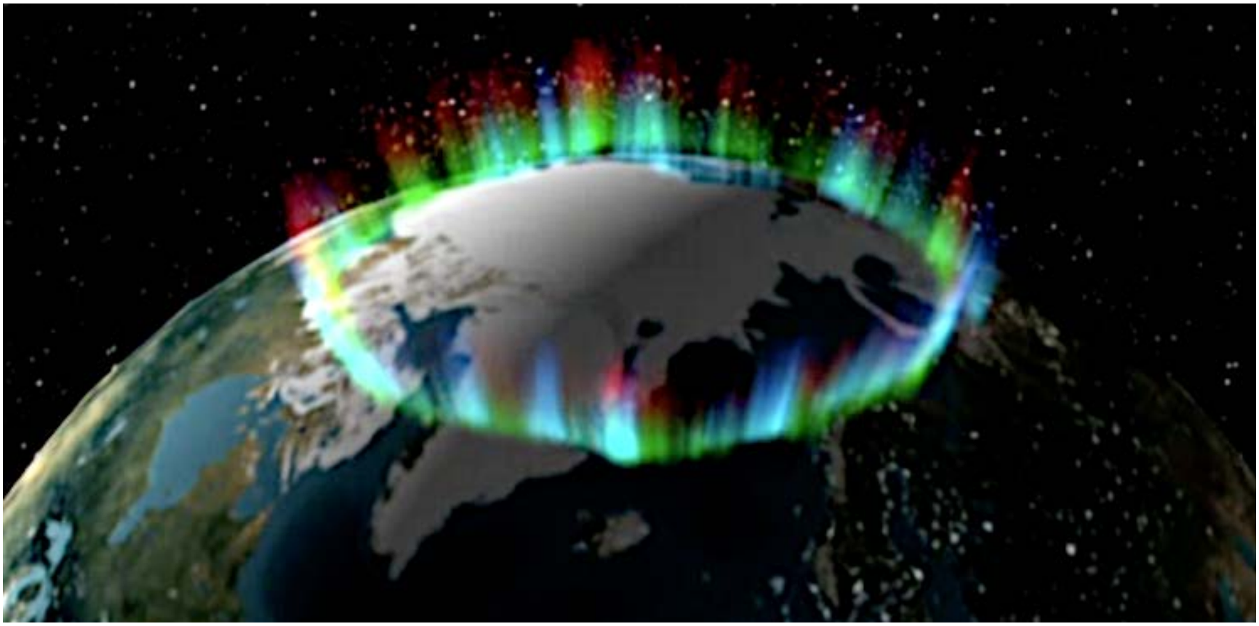




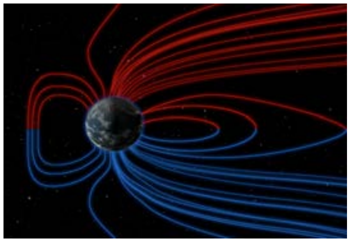
Pre-CME Impact CME Impact Imminent Compression/Coupling

The compression of the field affects the Van Allen radiation belts and the ionosphere, whereby during CME impacts, electrons are driven downward towards the atmosphere on the sun-facing side. In the right-side image above you can picture how plasma pressure of the CME might force the Van Allen belts (pictured below) into the atmosphere.



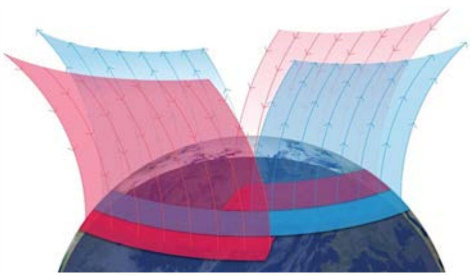


A key essence of the geomagnetic storm can be found at the poles.



Earth's primary magnetic field connects to the Earth at the polar regions. During CME and coronal hole stream impacts, the magnetosphere helps guide the impacting particles around to the poles. On days when there are exceptional auroras, it is almost certain that a CME or coronal hole stream has impacted our magnetic field and caused a geomagnetic storm.

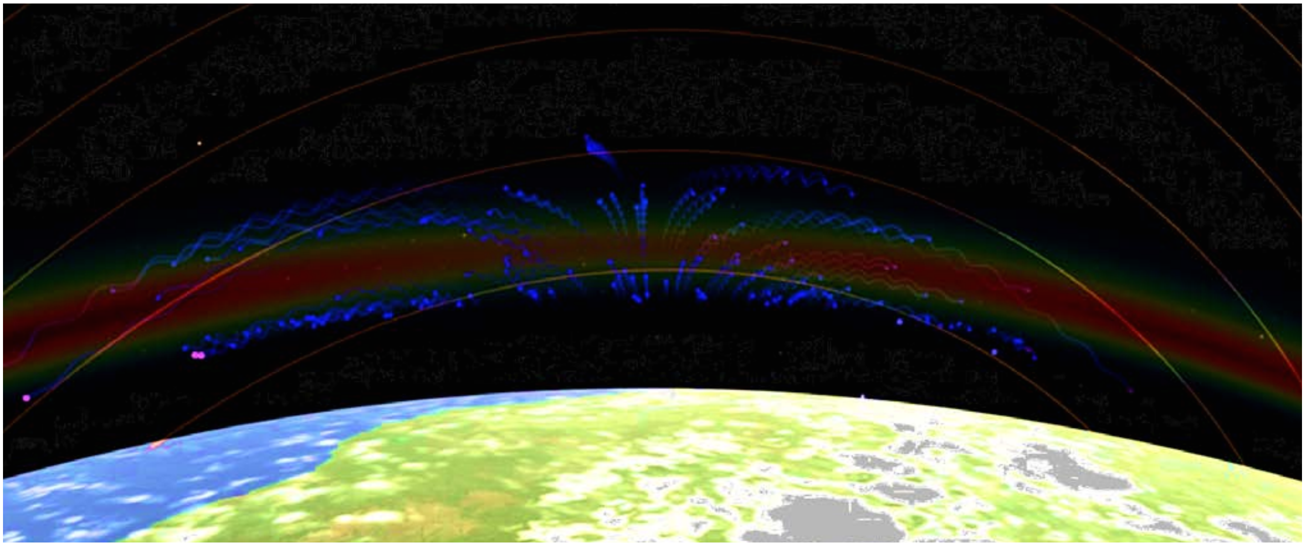
The aurorae are not randomly situated in a circle around the polar regions, and it is no coincidence that only during the strongest geomagnetic storms do the aurorae spread to lower latitudes- a ring of energy called the auroral electrojet exists at the poles and it is fed by the particles directed along Earth's magnetosphere to these polar regions.



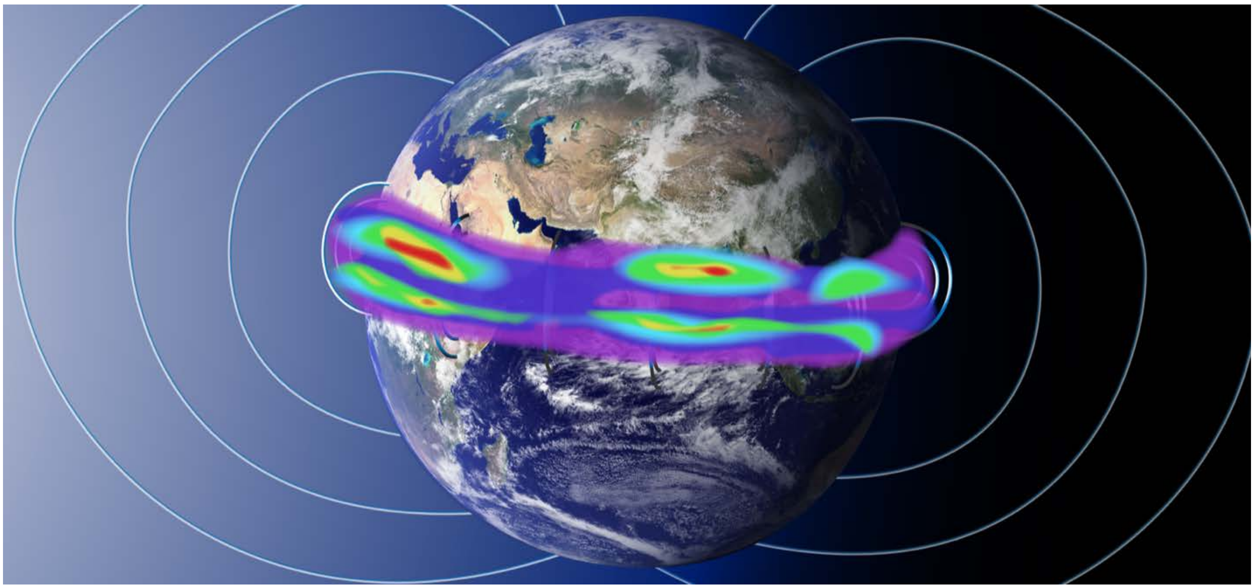
Northern Auroral Electrojet and Field-Aligned Current Connections; from ESA.int

A third ring called the "equatorial electrojet" sits above the tropical regions, but does not often present itself visually with auroras. The equatorial electrojet forms from an ion fountain above the equator (pictured on next page) and is strengthened via magnetosphere compression (rather than energy deflected to the auroral zones). That compression pushes particles into the ionosphere and upper atmosphere from the Earth's magnetic fields, Van Allen belts, and the ionosphere itself. Both polar electrojets and the equatorial electrojet are found in the ionosphere.

Space weather impacts enhance and strengthen the electrojets.



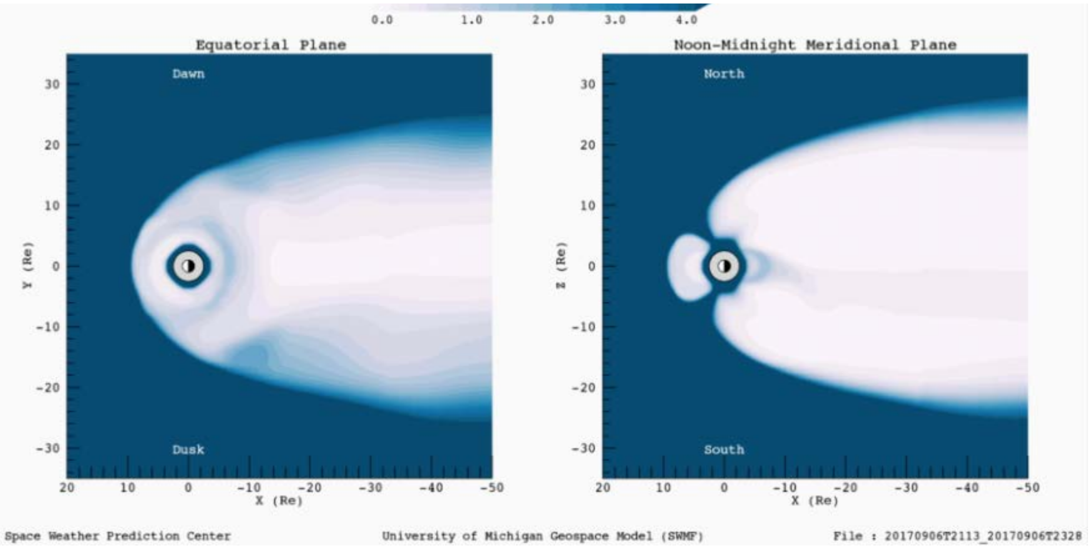
The image above shows us positioned on the equator, looking directly across the equator at the fountain of ions that constantly eject – the equatorial ion fountain. The image below shows the stronger return where the ions fall back down. Both images are from NASA.gov.



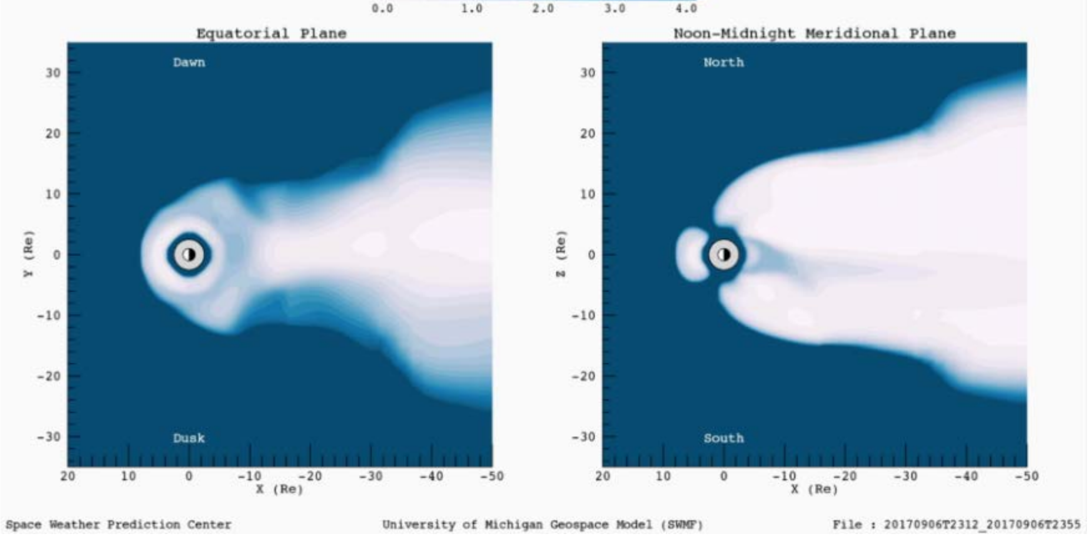
CME impact compression of the magnetic fields (thin arches) will intensify the particles' downward flow. This is how the equatorial electrojet is intensified, largely with Earth's own particles, whereas those same arching fields are driving the solar particles to the poles to intensify the auroral electrojets. When a CME impacts the planet and energizes the ionospheric electrojets, they can further create or "induce" powerful electric currents in the atmosphere and the ground. As we will learn in Chapters 4 - 7, these currents are a critical piece of solar-terrestrial physics, and they influence a wide range of relevant events. There are no absolute general rules when it comes to CMEs and coronal hole streams; each is different and somewhat unpredictable beyond its general speed and density. Every time a CME strikes Earth, everything electromagnetically vulnerable

(technology, water, metal) is at risk of taking an amount of that energy that exceeds the system limitations, whether that system is the power grid on the street, a stream of water vapor in the atmosphere, or the circuit in your brain.

This section ends with two density-model displays of Earth's magnetic field blown to the right by the solar wind, and the sun implied to be off to the left. The top image shows a full magnetic shell (white, high density of particles due to strong and stable field) while the bottom image shows our planetary shield just after CME impact. Images on the left side show the equatorial plane, while images on the right show noon-midnight plane.



Above - Broad, stable magnetosphere. Bottom - CME-compressed magnetosphere



The disruption to Earth's magnetic field not only adds solar energy to Earth's system, but the compression of the field forces that higher amount of energy to cycle through a circuit of even smaller size than normal; this excess energy directly penetrates to the ionospheric layer, induces the

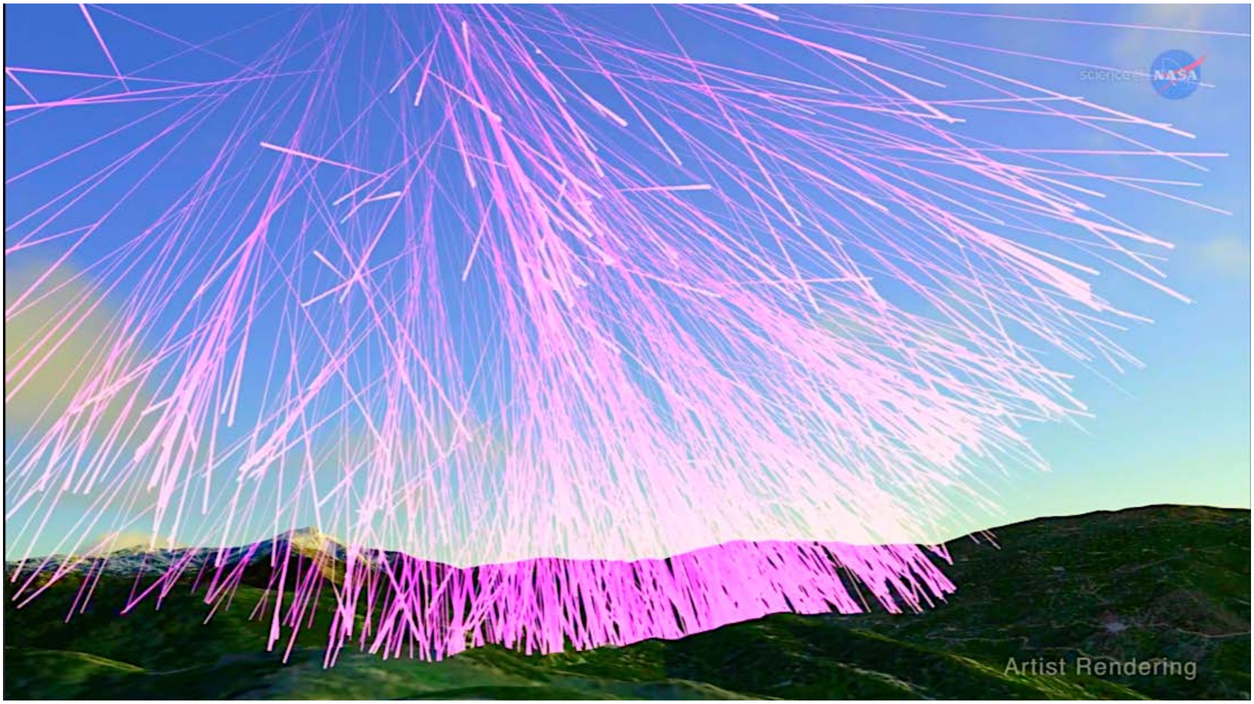
electric currents on Earth, and even resonates magnetic fields near the surface to produce very low, ultra-low, and extremely low frequencies (VLF, ULF, ELF).

Key Points:

1) Intensified solar wind from CMEs or coronal holes may disrupt Earth's magnetic field and add energy to the system, causing a geomagnetic storm.

2) Geomagnetic conditions are reported on the "Kp index" ranging from 0-9, where 0-3 are considered calm conditions, 4 is considered unstable condition, and 5-9 are considered storm conditions.

3) Geomagnetic storms cause enhanced aurorae, excite the ionospheric electrojets and can produce electric currents in the atmosphere and the ground that influence many aspects of Earth and its inhabitants (us). This concept is central to Chapters 4-7.



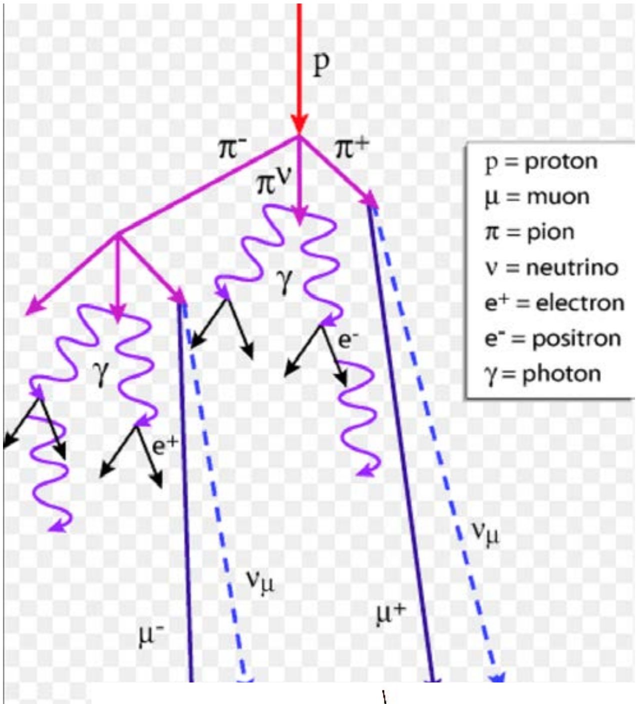
1.9 Cosmic Rays

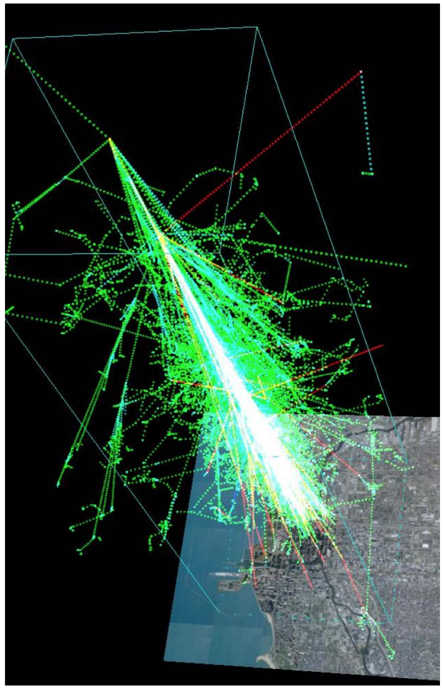
Earth’s magnetic field protects the Earth from more than just the sun’s rays and solar wind; it protects against most interstellar and intergalactic waves and particles. While the energetic waves are usually well-deflected, many high-energy particles can penetrate the magnetosphere, and can even penetrate to the core of the Earth. Those high-energy particles consist of atomic nuclei stripped of electrons called **Galactic Cosmic Rays (GCR)**. GCR are mostly protons and hydrogen nuclei, but other atomic nuclei such as iron, selenium, magnesium, oxygen, carbon and most other elements have been detected in various amounts.

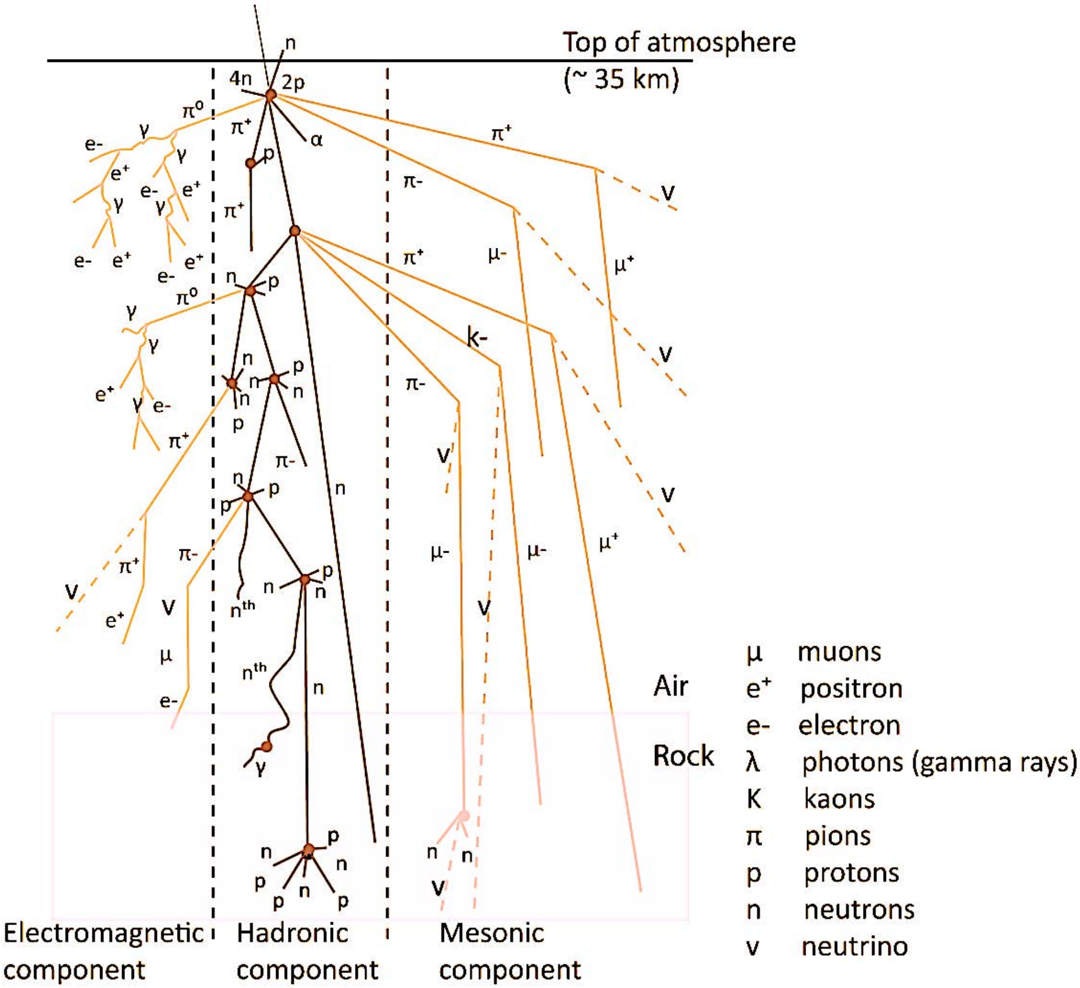
These particles vary in energy, and despite the fact that our magnetosphere blocks a great deal of them, enough still penetrate to strike every square meter of the upper atmosphere every second. The highest energy (and most penetrating) particles may only strike once per year in a square kilometer area, and those will reach the Earth’s mantle or core. Lower energy GCR usually hit atmospheric particles. Just one low energy GCR can shower a few acres with energetic particle decay (image above). Now picture that one particle decay shower is accompanied by another starting at every square meter of the upper atmosphere, overlapping with one another every second; the ground level is constantly showered in the cascade.

This break-out of particles is of critical importance to Chapters 4 - 7. In the images on the next page, we find depictions of the shower of particles from one GCR, called a “cosmic ray cascade”, with explanations on the following page.

Images on the next page come from the HAWC Observatory (top left), PhysicsOpenLab.org (top right), and AntarcticGlaciers.org (bottom).


p
π-
π+
πν
γ
e-
e+
νμ
μ-
μ+
p = proton
μ = muon
π = pion
ν = neutrino
e+ = electron
e- = positron
γ = photon

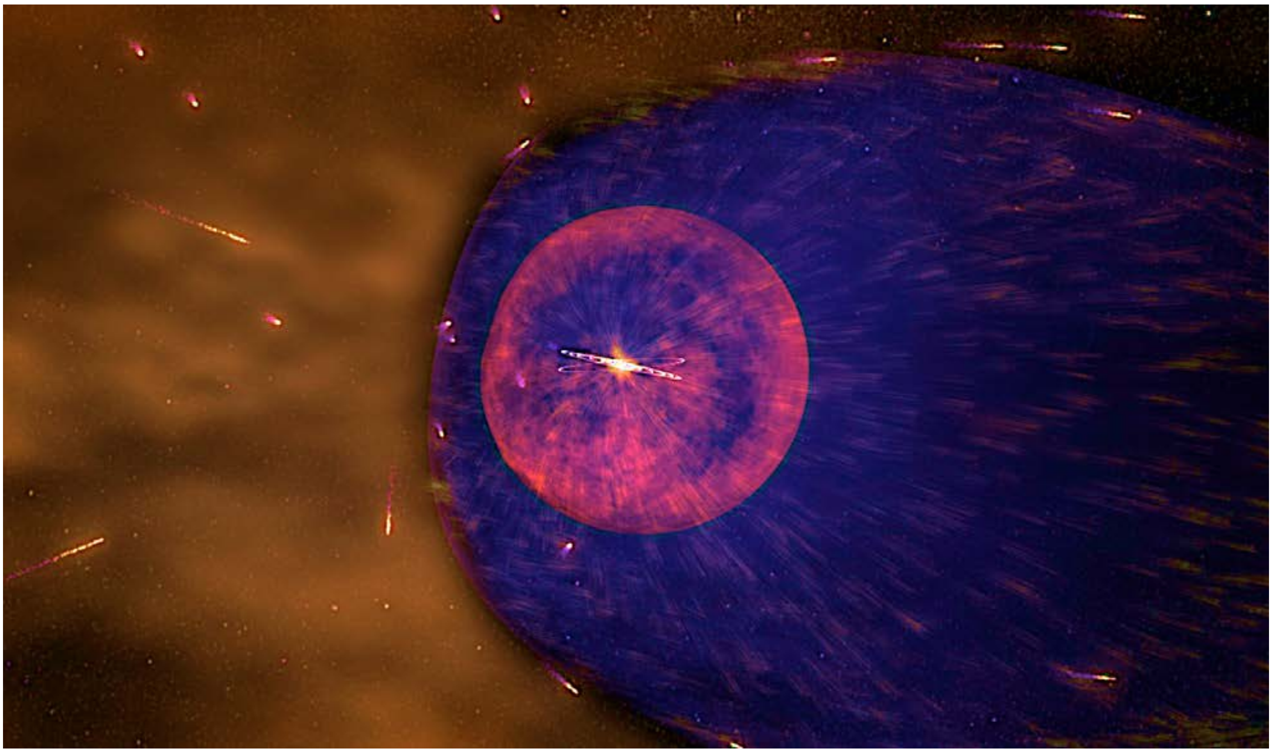



Top of atmosphere
(~ 35 km)
n
4n
2p
π0
π+
π-
α
K-
μ-
μ+
e-
e+
γ
v
nth
Air
Rock
Electromagnetic component
Hadronic component
Mesonic component
μ muons
e+ positron
e- electron
λ photons (gamma rays)
K kaons
π pions
p protons
n neutrons
v neutrino

There is not yet any standard means of describing the cascade effects (a confounding aspect of the field), which is why the annotation and charge symbols are not the same in the images on the previous page. Each of those massive lightning-looking breakouts of particles (cascades) starts with just one GCR hitting the upper atmosphere. If one were to similarly trace all the cosmic ray cascades at any given time you would not see anything else in the picture. Good news: most of the particles pass right through our bodies, harmlessly, about 33 times every second.

While it can seem scary, we all live inside of this cascade every day and have been doing so our entire lives. Despite their ubiquity in our existence, the variation of these GCR are able to affect numerous geophysical and biophysical processes. What causes these variations in GCR rates? The sun and Earth's magnetic field.

The Earth actually has two magnetic shields against cosmic rays: our planet's own magnetosphere, and the sun's magnetic field, called the "heliosphere". The solar wind electric field and IMF streaming out past Pluto protect the solar system just as Earth's magnetic field bubble protects our planet alone. **The GCR are charged (+ or -), so the IMF and electric field of solar wind act like a shield against the rest of the galaxy and the universe.**



NASA/SVS image of sun's magnetic bubble, protecting the solar system from cosmic rays. NASA.gov

During times when solar activity (sunspots, solar flares, CMEs) is high, cosmic rays are low due to extra energy and particle shockwaves blocking them. During periods of a quiet sun, we see far more cosmic rays, as the electric field of solar wind becomes less dense and the IMF is less energized. This inverse relationship (anticorrelation) is entirely based on the premise with which we began: the important aspects of space weather are electromagnetic and involve how the sun's activity affects the solar wind. High solar activity enhances the solar wind, and therefore, enhances one of the shields

against cosmic rays, and does so for the exact same electromagnetic reason that Earth's magnetosphere blocks energy from the sun.

On a short timescale, an event known as a "Forbush Decrease" exhibits this modulation. A Forbush decrease refers to the sudden drop in cosmic rays that occurs just before and during Earth-impact from CMEs. In the same way that the electric field of solar wind acts like an electromagnetic shield for the entire solar system, when intensified solar wind streams such as CMEs hit Earth, those streams help to block cosmic rays. Think of this like Earth technically being inside of a giant electromagnetic cloud (extra shielding) during CME impact, even if that cloud is having its own electromagnetic effects on our planet, like geomagnetic storms.

Key Points:

1) Galactic Cosmic Rays (GCR) come from outside the solar system- even outside the Milky Way galaxy.

2) GCR are energetic atomic nuclei stripped of electrons, which create particle cascades when they hit the atmosphere, or can penetrate the ground.

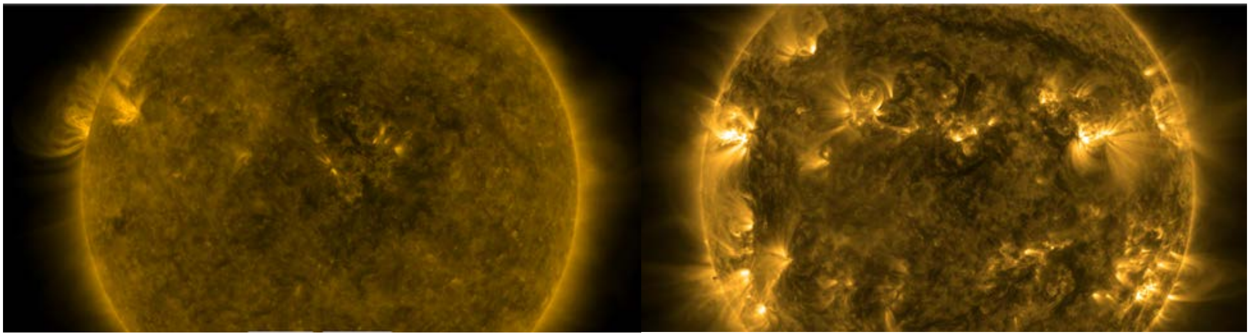
3) GCR hit every square meter of the upper atmosphere every second, but the highest-energy GCR strike only once per square km/yr.

4) GCR are anticorrelated (inverse relationship) with solar activity (flares, CMEs).

5) When a CME impacts Earth (surrounds the planet) there is a drop in cosmic rays, called a Forbush Decrease.

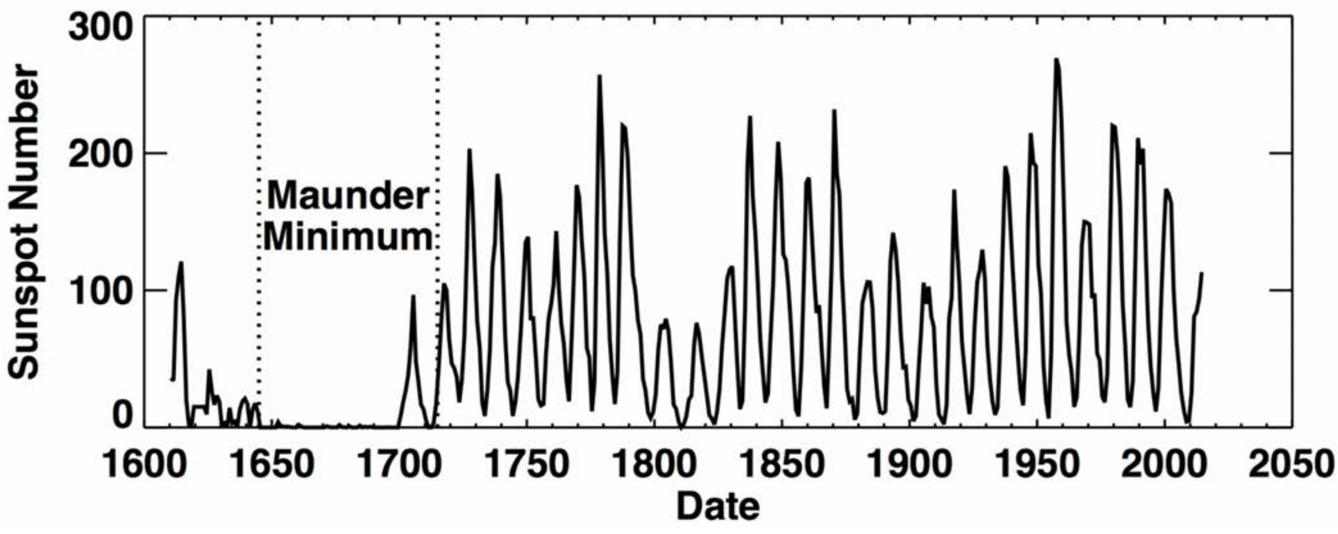
2.0 Solar Cycles

Solar cycles are fundamental to understanding space weather patterns and the effects they can have on our planet.

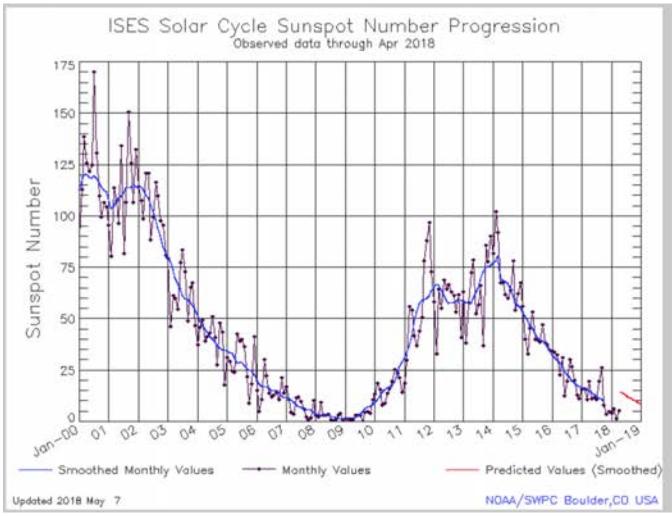


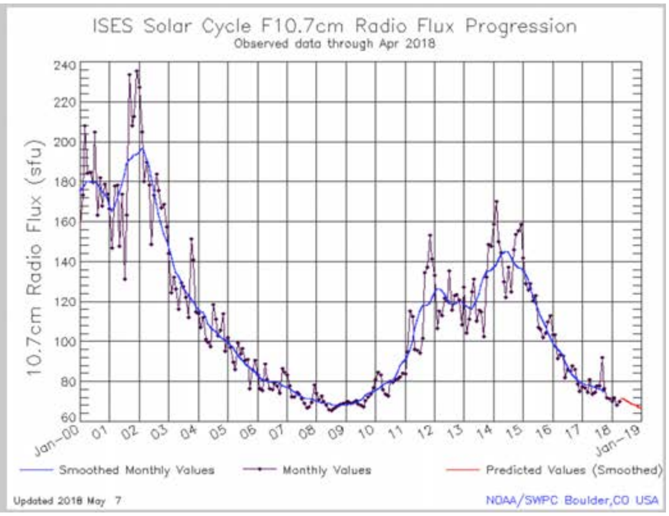
2.1 The 11-Year Cycle

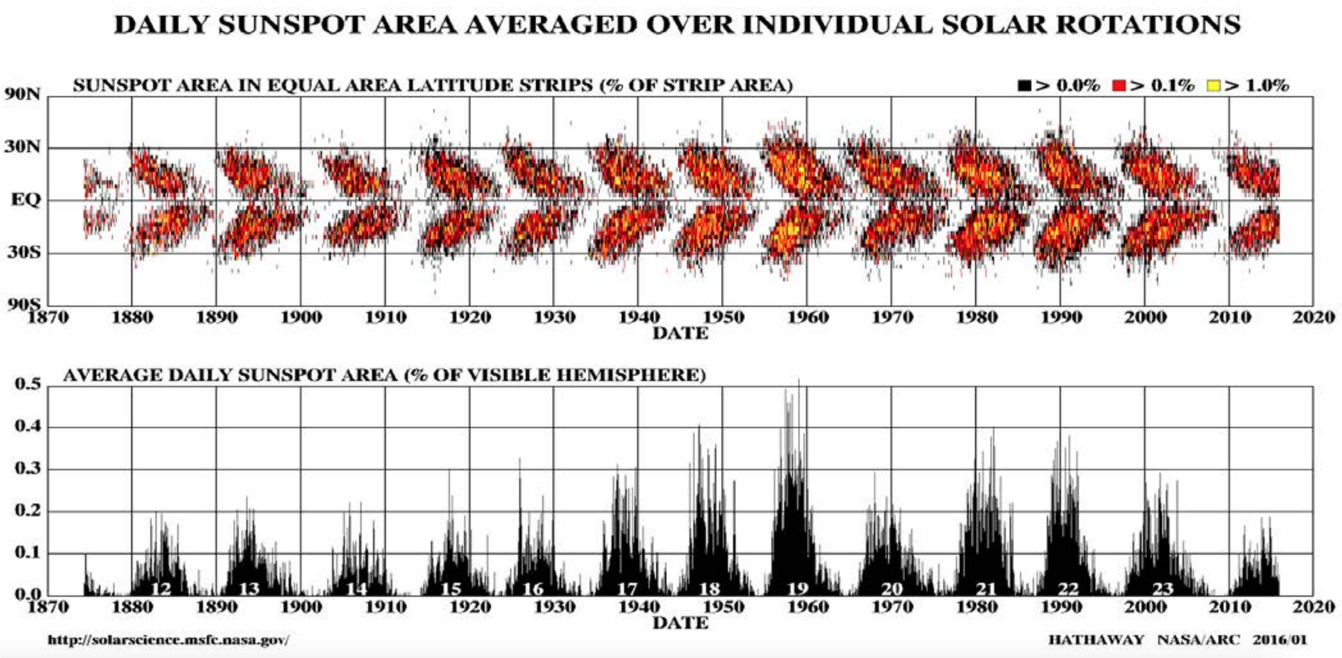
The most well-known and fundamental solar cycle is ~11 years long. It can range from 9 to 13 years and is often called the "sunspot cycle". There is a predictable rise and fall to sunspot activity, and therefore, a predictable rise and fall to solar flares, CMEs, SEP events, geomagnetic storms and cosmic ray activity. Over this ~11-year period, sunspots have a minimum and maximum of activity, which is depicted above in the left and right SDO images, respectively. In the images below and on the next page, we see the undulation of the 11-year cycle on the sun over various timescales.



Marshall Space Flight Center, NASA.gov, showing the spikes in sunspot production every ~11 years.



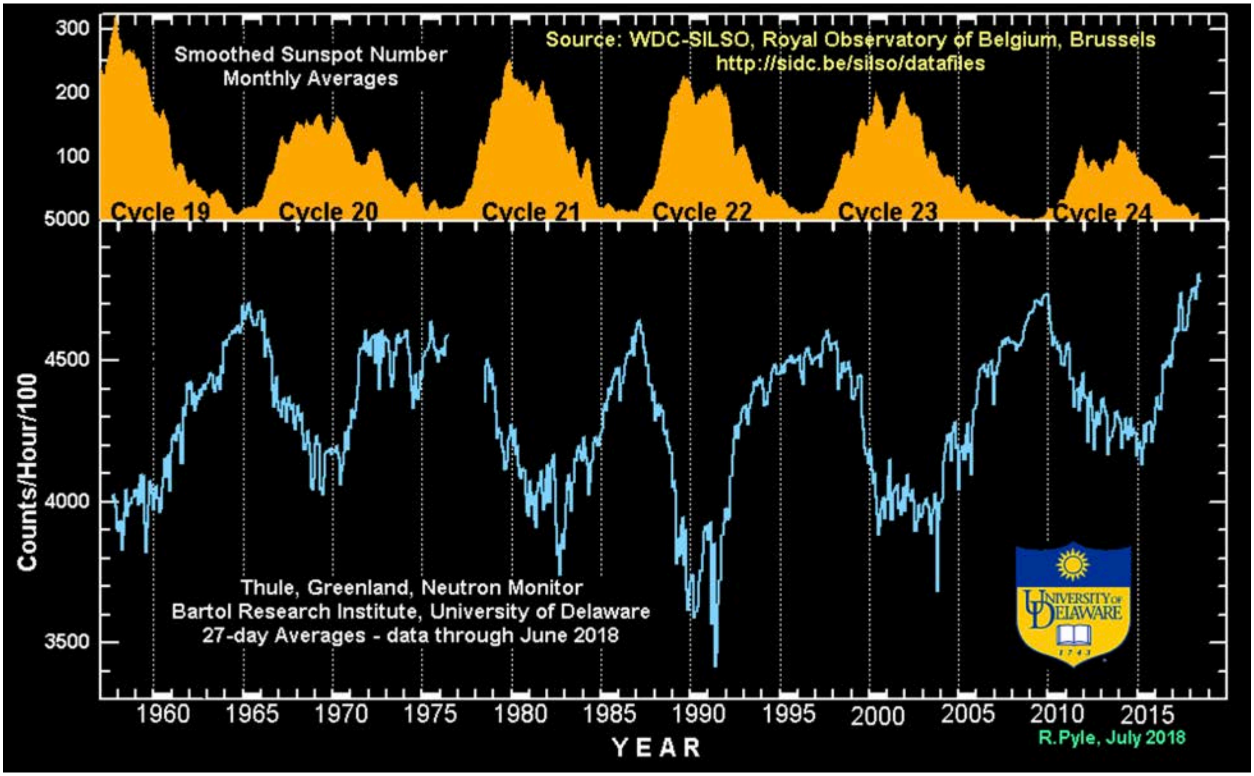




These images come from NASA's Marshall Space Flight Center and David Hathaway (NASA Solar Science Legend). You can see how the cycles are not always the same size, but they are approximately the same duration and distance apart, ~11yrs. The orange and red 'butterfly diagram' shows where the sunspots appeared over time in heliographic latitude (y-axis); they trend towards the equator over the cycle and then get back in line at higher latitudes for the next one.

It is called the sunspot cycle because for centuries the sunspot has been the central focus of space weather. Patterns of solar flares, CMEs and geomagnetic storms rise and fall on the same cycle, but our ancestors knew little of their occurrence or affects apart from seeing the aurorae. For a long time, this cycle was gauged with sunspot observations by reflection telescopes and horizon sunspot watching, which established the cycles that we can track in greater detail today. We now have much more information about things such as coronal holes and plasma filaments, and even the radio wave output of the sun (top-right image) which matches the sunspot cycle. There are MANY ways we could in-fact gauge the sunspot cycle.

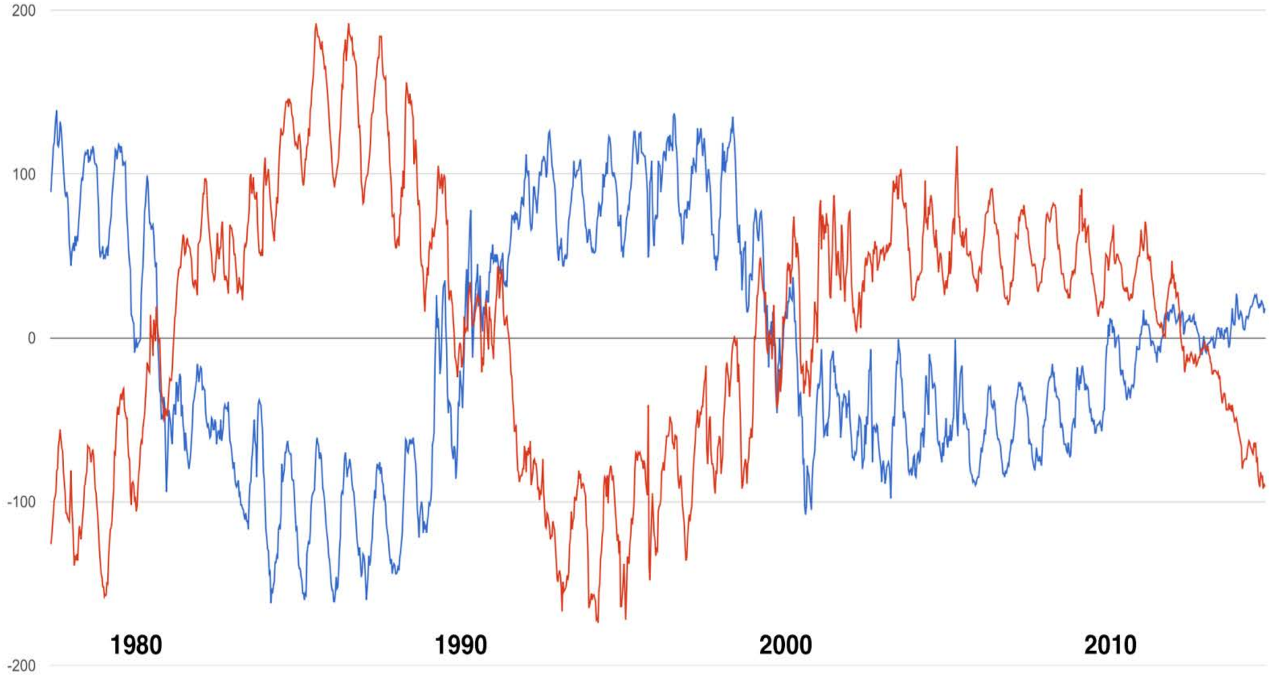
For cosmic rays, the curve over time is roughly the same, except it peaks when sunspots are at minimum, and drops into cosmic ray minimum when sunspots are more numerous at their maximum (anticorrelation). The chart below shows how sunspots (orange) and cosmic rays (blue) have an inverse relationship.



The more we learn about space weather, the more important cosmic rays seem to be to solar-terrestrial physics, and the more things that sunspots must compete with on the other side of the table. So, if cosmic rays peak oppositely of sunspots on the same cyclical timeline, are there different ways to judge maximum and minimum of the cycle?

There is another feature on the sun that also follows a cycle opposite to sunspots; it matches the cosmic ray maximum/minimum phases and is considered the primary driver of sunspots and flare activity: **The Solar Polar Magnetic Fields (SPF)**. The SPF are interplanetary magnetic fields (IMF) just like other open solar magnetic fields streaming out into space, except the SPF are measured only from the high-latitude regions of our star.

The sun's magnetic field reverses every sunspot cycle, with the north and south magnetic polarity switching hemispheres. This feature determines when one sunspot cycle begins and when it ends. Many of the world's best solar physicists believe it also determines how many sunspots will come in a given cycle, and how active those sunspots will be. The SPF determines where the coronal holes and plasma filaments are found (heliographic latitude), and what the character of the solar wind current sheet/IMF will be. The SPF are actually the driving force behind many of the solar phenomena discussed so far. The next image shows the SPF data from Stanford's Wilcox Solar Observatory:



The curves reverse polarity (cross the 0 “baseline”) every ~11 years, triggering sunspot maximum. However, this is the minimum magnetism of the SPF, and also the GCR minimum. When the SPF are strong, so are GCR, but we are generally in sunspot minimum.

The blue curve is the northern field strength and red is the south. The short-duration waveform between the larger 11-year reversal waves are approximately one year long each. These shorter waveforms are caused by Earth’s slightly tilted orbit, putting us closer to one solar pole than the other each half of the year. In the northern spring we are slightly south of the solar equator and in northern autumn we are slightly north.

Since it is appropriate to consider the solar polar fields (SPF) to be the driving force behind the 11-year sunspot cycle, it is also the indirect driver of cosmic ray levels at earth- via that sunspot activity. As we will see later in this book, these fields not only drive actions on the sun, but are able to affect the Earth themselves.

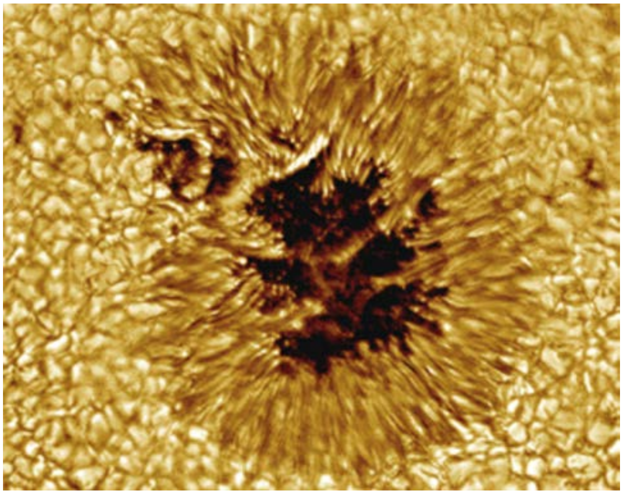
Key Points:

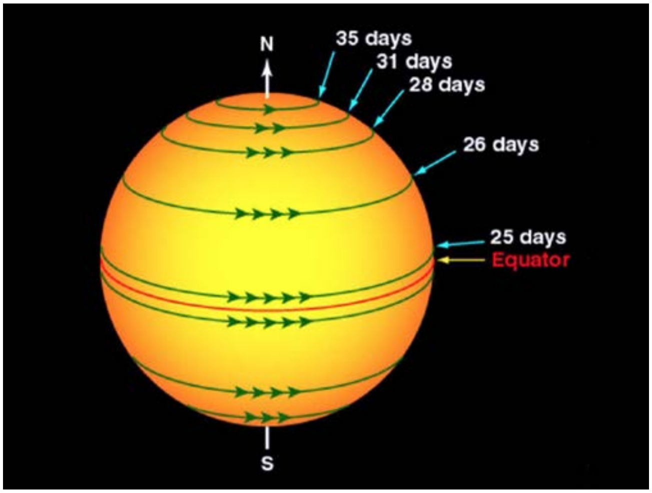
1) The most recognizable and important cycle on the sun is often called the sunspot cycle. It is ~11 years long, which dictates the rise and fall of sunspot production and their solar flare activity. CMEs, SEP events and geomagnetic storms follow this same cycle.

2) The sunspot cycle is correlated with solar flares, CMEs, geomagnetic storms and SEP events, and is anticorrelated with cosmic rays (high sunspots = low GCR).

3) The SPF have an ~11-year cycle as well, which drives the sunspot cycle, and is anti-correlated with sunspot numbers.

4) The SPF are high-latitude IMF.



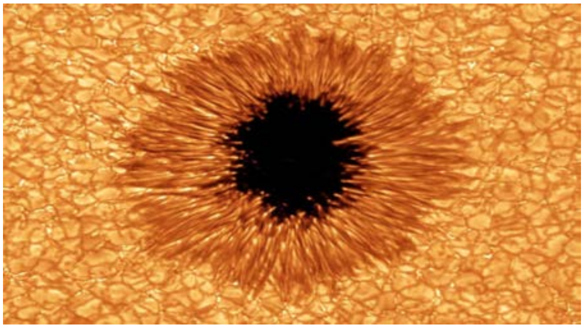


Sunspot image from SDO (left) and solar differential rotation diagram from SolarCycleScience.com (right)

2.2 Other Solar Cycles

The ~11-year cycle involving the SPF, sunspots, cosmic rays, solar flares, etc. is the most recognizable large-scale cycle of the sun, but there are various other cycles on both large and small temporal scales. There appears to be evidence of solar cycles as long as 1000+ years, but for this book we will mostly focus on shorter timescales until Chapter 8.

There are several oscillations and cycles on our star that are important for gauging climate events on Earth, and many that are not. Within and above sunspots we see oscillations of 1 to 2 minutes, 3 minutes, and 5 minutes. These are largely irrelevant for solar-terrestrial (sun-Earth interaction) science, albeit important for solar physics itself.



Numerous other periodicities, ranging from several minutes to a few months to a few years, have been proposed, but also disputed, and none has been proven to be as robust as the ~11-year oscillation and its harmonics. Additionally, these other cycles are not easily discernible in climate data, and many are only truly relevant for space weather forecasting and analysis.

Solar cycles longer than the ~11-year cycle are often far more noticeable in climate data than shorter ones, and numerous such cycles have been identified and proposed for further investigation. On the next page are some interesting cycles that are good to know, of various lengths, many of which will be important later in this book:

~28 Days: The length of one solar day (1 solar rotation). The polar regions turn a little slower (+30 days), and the equator can spin around in as fast as 25 days. We call this ‘differential rotation’ and it is depicted in the top-right image on the previous page.

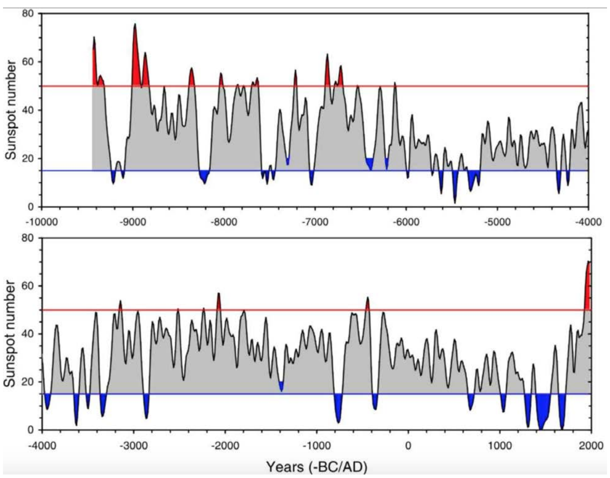
~6 Months: For reasons not-entirely understood, the Earth is more vulnerable to geomagnetic storms during the equinox than solstice periods. This could be due to the tilt of earth’s axis of Earth being most misaligned with the sun during the equinox.

~22 Years (Hale Cycle): As the sun’s polar magnetic fields reverse every ~11 years, a full magnetic cycle is two ~11-year cycles (See the SPF graphic in Section 2.1). Numerous other patterns have been discovered, such as the ‘even-odd’ rule; for unknown reasons, an odd-numbered solar cycle is usually stronger than the even-numbered cycle that came before it. This cycle appears often in long-term climate data as well, along with its harmonic cycles, many of which are listed below.

~44 Years (11/22-year harmonic): A well-known likely-harmonic of the 11/22-year cycles can be seen in a hemispheric asymmetry on the sun, whereby every four ~11-year cycles, the opposite hemisphere of the sun gets active first during the solar cycle. It is rare that north and south are in sync in their rise and fall in activity over the ~11-year cycle, and this “lagging behind” of one hemisphere tends to persist for four sunspot cycles, or two Hale cycles of the sun. (Murakozy 2016; Abbott 1937).

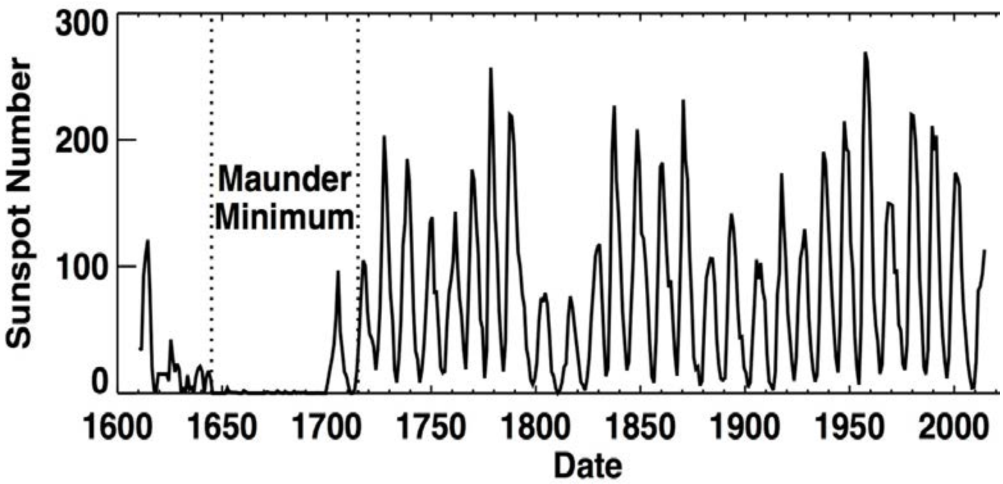
~80 - 88 Years (11/22-year harmonic): A well-known oscillation of solar activity over ~80 years is known to occur, often called the Gleissberg cycle. It is probably another harmonic of the sunspots/polar field cycles, with the variability due to the variability in the ~11-year cycle itself. This cycle is easily seen in radiocarbon data, with some evidence in the geomagnetic data and auroral records. This cycle also matches Uranus’ orbital period of ~84 years, and since Jupiter’s orbit is ~10-11 years, these types of coincidences are worth noting in your mental archive.

~200 Years: A much debated and often differently named cycle has been shown in radiocarbon data but is not easily noticeable over long-term sunspot reconstructions. However, a harmonic of this cycle can easily be seen in long-term sunspot data.

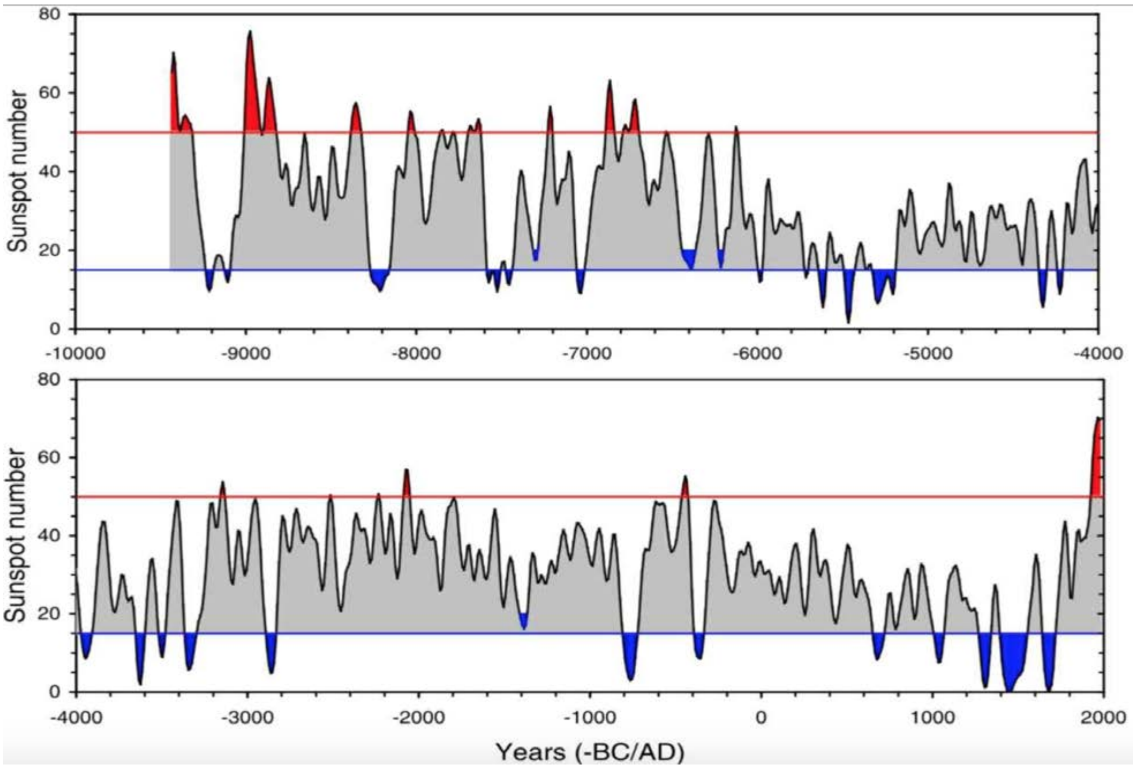


~400 - 440 Years (Grand Solar Cycle): Long-term reconstructions of sunspot data, over hundreds to thousands of years, look very similar to shorter-term data. This image is one such reconstruction from Ilya Usoskin, and it demonstrates how these peaks and troughs occur at quasi-regular intervals, even if their amplitude (height) varies a great deal. We saw that exact same pattern in sunspot numbers over the ~11-year cycle, in which regular cycles varied in strength but not in their duration (wavelength).

The next image shows the current grand solar cycle from the last grand minimum (Maunder Minimum), through the grand maximum just after 1950 and into the decline now. This period spans the time since the last blue spike on the previous image.



Many forecasters, including this author, see every sign that the sun is heading for another grand minimum this century, and the start of another grand solar cycle. The current grand maximum is the highest solar activity (red) since the exit from the last glacial period more than 10,000 years ago. The latest cold period, the so-called "Little Ice Age," happened from 1400-1700, during the ultra-low solar activity (blue) seen just before this current grand maximum. The little ice age ended when the Maunder Minimum ended around 1700.



Finally, there is an ~2400-year cycle called the Hallstatt Cycle, which we will discuss more in Chapter 8.

Key Points:

1) The sun is generally considered to rotate in ~28 days, but ‘differential rotation’ causes the poles to rotate in ~30 days while the equator of the sun may rotate in as little as 25 days.

2) Harmonics of the 11-year cycle of ~22, 40-44, and 80-88 years are evident in both solar phenomena and terrestrial (Earth-based) data.

3) The grand solar cycle of ~400-440 years includes a ‘grand minimum’ and ‘grand maximum’; the modern grand maximum peaked in the mid-late 1900s and was the strongest grand maximum in more than 10,000 years.

4) Many forecasters predict the next grand solar minimum will begin this century.

3.0 Introduction to Solar (Space Weather) Climate Forcing

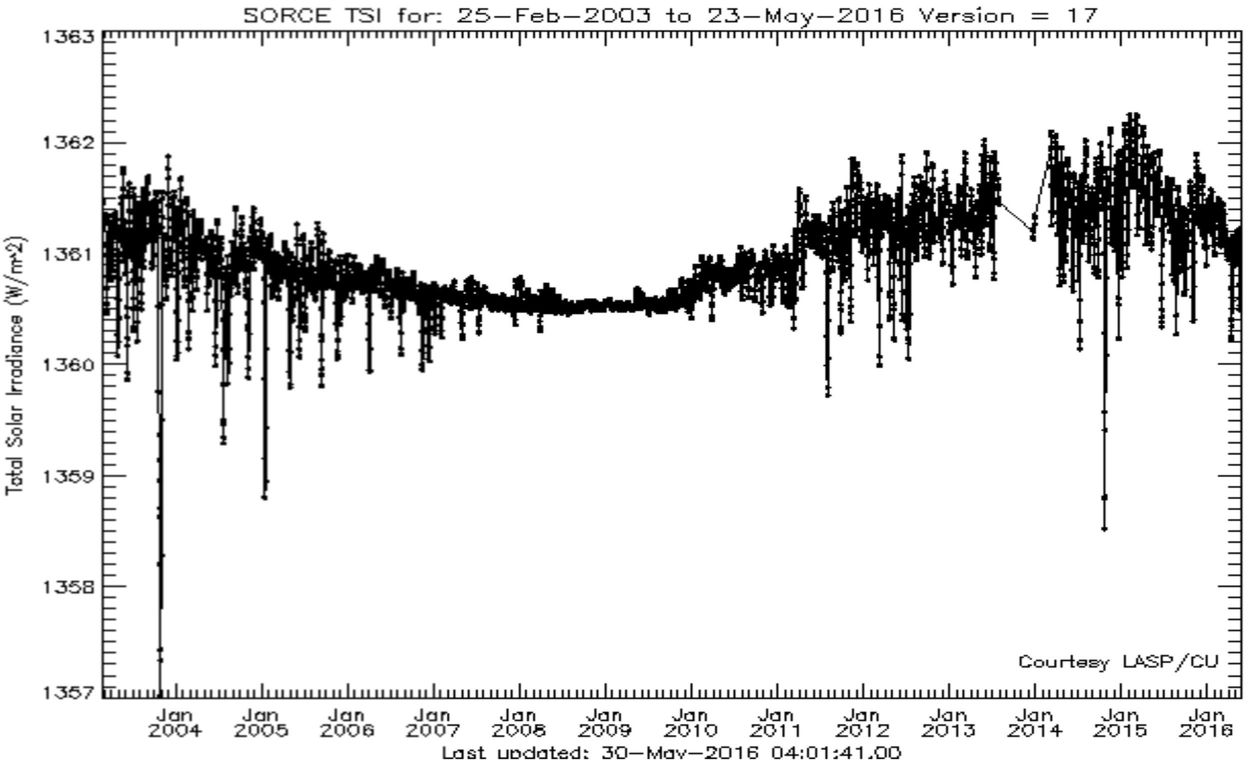
0.1%

3.1 The Historical Dominance of the Total Solar Irradiance (TSI) Model

Climate science is currently marred by the single greatest blunder in the history of geophysics: In official climate models, there is only 0.1% solar variability over the 11-year cycle in terms of influencing Earth's climate.

Until the last decade, very few studies of solar forcing on Earth's climate looked at anything other than sunspots or total solar irradiance (TSI). There has been a prevailing theory that the sun is relatively constant in its energetic output (in terms of heating the Earth) and that its effect on the climate is minimal compared with anthropogenic forcing (human pollution, deforestation, etc.). This has come to be known as "the solar constant"- and this is the blunder. While we should all strive to keep our atmosphere, hydrological system and soil cleaner, we should also strive for correct science.

TSI (or the similar index "Solar Spectral Irradiance") measures watt energy input to the atmosphere by sunlight. Images like the one on the next page are emblematic of the history of solar forcing. We have data and reconstructions going back centuries, but this short window provided by the Laboratory for Atmospheric and Space Physics essentially shows what the entire timeline shows: TSI and Solar Spectral Irradiance (SSI) vary by approximately 0.1% over the ~11-year sunspot cycle. That is 1/10th of 1%.



Indeed, these TSI readings match the ~11-year frequency of the sunspots and radio waves we saw in Chapter 2, but fluctuate in a much smaller range. **Since this 0.1% variability cycle perfectly matches the sunspot variability, it has been considered that the practical effect of this ~11-year fluctuation is imperceptible and negligible in terms of its effects on the global climate system.**

This notion has been so pervasive that the global climate science leader, the UN's International Panel on Climate Change (IPCC), placed 'solar forcing' completely outside the scope of its investigation, which has only focused on human pollution, deforestation, urban development effects, and other manifestations of human activity.

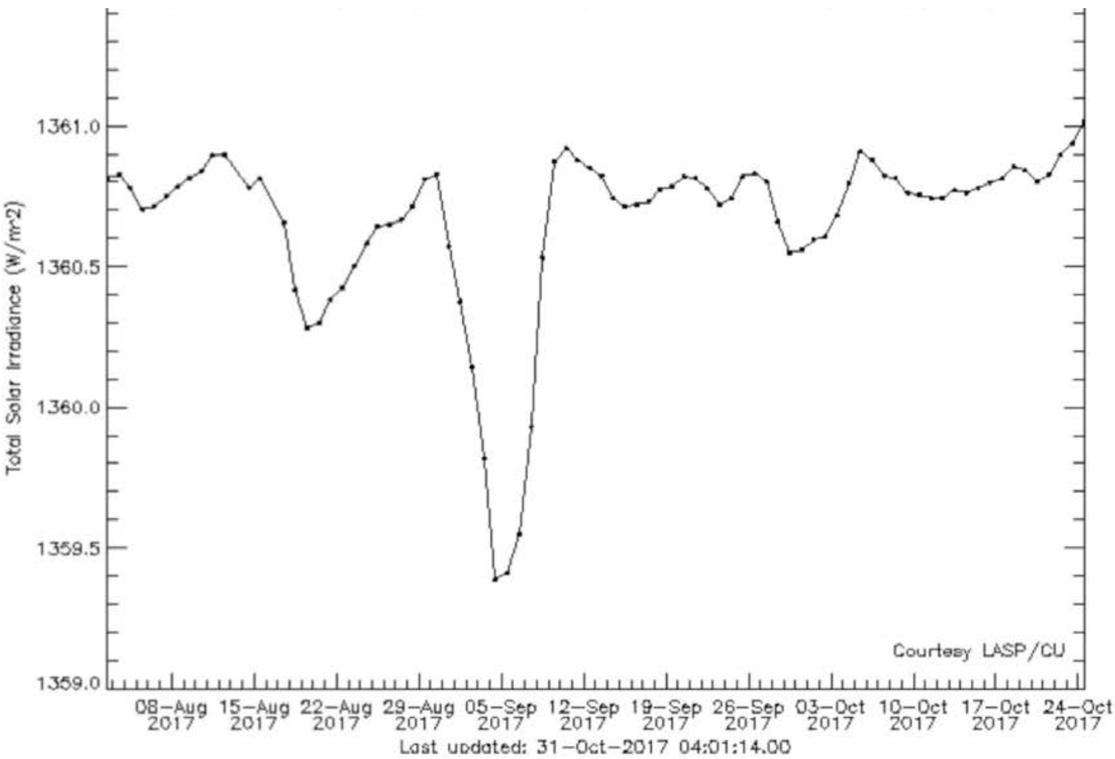
So, what is the problem with that? **Answer: The enormous drops in the data curve!**

What are the large spikes downward in the graph above? They represent times when massive sunspot groups produced large solar flares and CMEs. Technically, within the range measured by TSI and SSI readings, those times do show a sudden drop in certain UV wavelengths, the primary actors on Earth's upper atmosphere.

However, in reality this represents a movement in data that is opposite of the actual solar influence, which in fact would be a sharp increase in energy to Earth via X-rays and particles.

One of the best examples of this flaw occurred in early September 2017, with the largest solar flare in 12 years. Due to its direct effects being on Earth layers other than the upper atmosphere, this showed up as an enormous drop in solar energy received when it was a major surplus (next image).

The September 2017 event was one of the most tremendous space weather events on record, with ~1000x increases in particle and x-ray delivery, and it shows up as drop in solar forcing on the Earth.



Solar interaction at layers other than the upper atmosphere is a core concept of the later chapters, but at this early stage, you can understand this to mean that using TSI will offer a generally accurate long-term readout and trend of ultraviolet energy received by our upper atmosphere, but suffers in terms of climate change science because the most important energetic events show up as decreases in solar energy received. **Since the true effect of this energy does not go into climate models, the climatological effects we observe (and must account for) are attributed to human activity.** In section 1.7 we looked at a tremendous 10,000x-increase SEP event due to a solar flare and CME impact; that one showed up as a nearly 0.1% drop in solar energy to earth.

This has caused nearly 100% of the confusion surrounding solar climate forcing, and it is a colossal error. The simple fact is that the energy of strong flares, CMEs and geomagnetic storms affect the Earth in other ways than the near-constant UV output, leaving the prevailing solar dataset to indicate that the sun begins to give us less energy- when in fact the opposite is true.

In terms of solar flares, the X-ray energy received by Earth can vary by 10x over a sunspot cycle, with short-term activity offering 100x to 1000x the energy. In terms of particle radiation, there are almost never any SEP events during sunspot minimum and there are 10x to 100x fewer CMEs during those inactive periods as well. Geomagnetic storm activity falls during sunspot minimum by a factor of 10x to 20x. GCR fluctuations over the 11-year cycle, and during short-term space weather events, can be 5 to 10 % or more. This is all compared to 0.1% variability that has been in climate models throughout the modern evolution of the science.

Key Points:

1) TSI and SSI vary by 0.1% between sunspot maximum and sunspot minimum and have been the sole factors used to gauge the sun's influence over the weather/climate.

2) TSI /SSI are flawed measurements because the most energetic transfers from sun to Earth are recorded as low-energy periods.

3) The X-ray flux from solar flares, energetic particle storms and GCR can fluctuate much more than UV and upper-atmosphere heating over the same 11-year cycle.

4) Without a way to blame the sun, both the real climate forcing and the false negative signal that shows up with TSI/SSI must be accounted for by human forcing in the models. The forcing from solar flares, CMEs, and geomagnetic storms is in fact currently counted as being the fault of human carbon emissions.

3.2 The Fall of the Solar Constant

There is little debate that pollution of various forms, including carbon-based pollution, affects the environmental chemistry and system dynamics of Earth, including the climate. However, a simple problem has come about in climate science that requires a significant reassessment in the fields of climatology, meteorology, and solar-terrestrial physics. The image above followed a great decade of progress in solar-terrestrial physics, as key groups and interests across the planet begin to understand the full power of our star.

In 2013, it began to become clear that we were approaching 20 years of vastly overestimated global warming predictions. This was especially confusing because many of the drought, flood, and other extreme events seemed to be occurring as predicted. During this time, we saw higher CO^2 levels and faster rates of greenhouse-gas emission (driven mostly by countries in Asia) than ever, and yet a well-documented “global warming pause” occurred. It wasn’t until the 2015/2016 El Niño (one of the most intense on record) that temperatures finally moved back upward. The head of the IPCC, Dr. Pachauri, stepped down amidst controversy over a number of issues, including failed temperature forecasts. Even the record warmth of 2015/2016 was well below what had been predicted based on carbon emissions alone, and it had required one of the most severe El Niños in history to get us there.

While every model and explanation of human effect on global warming dictated that we should have seen a vast spike in global temperatures in the last two decades as CO^2 continued to rise, we saw a definitive plateau at the turn of the millennium, with record cold and snow events persisting and even intensifying across the northern hemisphere before the record El Niño began in 2015. We’ll see later in this book how ENSO (El Niño/La Niña) cycles are actually driven by the sun.

There is no doubt that the official climate forecasts have been able to predict the extremes of climate change with the exception of perhaps the most important piece: global warming. How could this be the case? How could they forecast the droughts, flood, storms, etc. … but miss the mark on temperature without the help of El Niño- especially when temperature was supposed to be driving the changes they forecasted? The paragraph pictured below is from one of the earliest IPCC reports, and its paradigm has prevailed; the IPCC is not looking at anything other than human activities.

> Fluctuations of climate occur on many scales as a result of natural processes; this is often referred to as natural **climate variability**. The **climate change** which we are addressing in this report is that which may occur over the next century as a result of human activities. More complete definitions of these terms can be found in WMO (1979) and WMO (1984).

By definition, the official global climate group has restricted “climate change” to ONLY be that driven by human activity. They do not exceed their mandate or re-examine the “solar constant” concept created in the 1970s, and by the time a few scientists began to figure out how limiting this was to real science, the paradigm had escalated to a political and financial juggernaut that placed all importance on the human-caused global warming story.

Even though the discourse has shifted from “global warming” to “climate change” (they had no choice) there has been little shift in political thinking, public discourse or scientific funding. Despite solar forcing slowly becoming a more-recognized aspect of climate science, researchers in this field continue to face hurdles like professional ostracism and bullying among their peers.

The climate of Earth has never been stable. Much of the Earth’s reconstructed history indicates that the Earth is not usually as benign to life as it has been since the 1700s. Between periodic ice ages, vastly hotter temperatures during the times of the dinosaurs, and even the stories of our ancestors (events so terrible they were blamed on gods) - it is likely that our planet is ever-changing and capable of throwing climate curveballs that simply have not occurred during the time of science. This is where energy from space comes into play.

Take the example of one solar flare, which can increase X-ray and EUV output by factors of 10 to 1000, and rarely lasts longer than a few hours. One solar flare will not increase the Watt energy delivered to Earth over time in any meaningful way, and in fact it will show up as a decrease in energy according to TSI/SSI measurements. However, as we will see in the following chapters, increases in flare energy, along with their SEP events, CME impacts, and geomagnetic storms, can reach thresholds of forcing, which are not reflected in long-term TSI data and which are not seen in 11-year, 22-year or longer sunspot cycle data.

Thresholds of Forcing. Certain space weather events are not variable in terms of percentages. They are a simple yes or no, on or off. When these threshold events are triggered, the use of TSI is no longer relevant for that time period, especially when it shows a decrease in energy to earth during high solar activity.

Consider the example of raw chicken: How dangerous is raw chicken at room temperature vs 99 º F? 150 º ? The answer is the same because at 150 º, the harmful bacteria in the chicken will still be alive and you run the risk of food poisoning. You could study dozens of temperatures from 0-150 º F and find similar levels of dangerous bacteria. Should we say that cook-temperature is not an important factor for food safety?

~

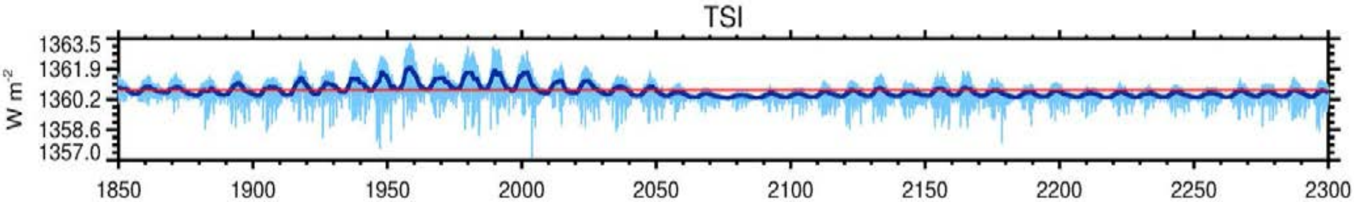
Obviously not, because something happens at ~165 º F: all the bacteria die. Once you hit a threshold event, the situation changes completely, and gauging the effect of temperature on the safety of that piece of chicken is suddenly relevant although it was not relevant before.

~

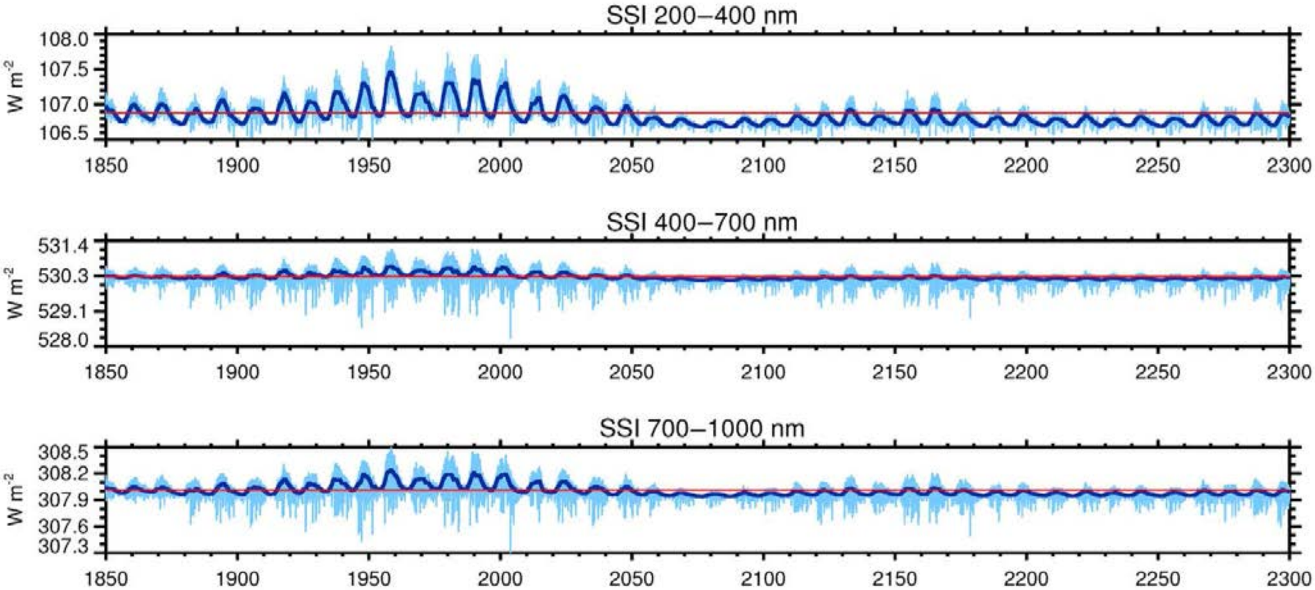
As of 2020, the scientific community has yet to **fully** understand the threshold events in space weather, instead being fooled by the same flaw in the initial chicken example in which one might look at a seemingly broad-enough range of data and misunderstand the food safety issues surrounding the raw chicken. Without the full set of facts, one cannot reach a reliable conclusion, and in this example, as with the climate, you don't need to be at 165 º (significant space weather activity) for very long in order to see a lasting effect that completely changes the chicken (climate).

The studies on space weather forcing of weather and climate have become numerous; hundreds of papers on the topic have been released just since 2010. Chapters 4-5 examine many of those articles to construct the framework of solar climate forcing, and of the future of many fields of related science.

While there remains great resistance to the acceptance of solar forcing into the mainstream climate change lexicon, glimmers of hope exist, like the recent solar particle dataset from a few of the world's best solar scientists (Matthes et al., 2017). The following image shows the existing record and forecast of TSI from Matthes et al. 2017, and indeed it is only fluctuating a fraction of a percent over the 11-year cycle.



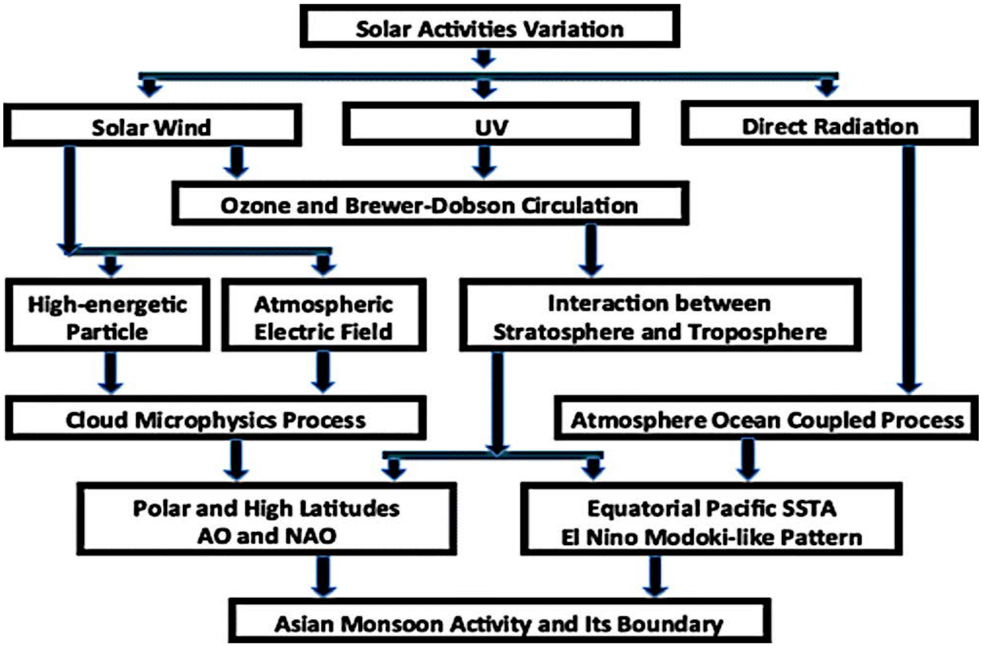
The next three image panels are the same type of plot from Matthes et al. 2017, except these are for three segments of ultraviolet light used to compute SSI. As we look at the UV spectra below, we find the highest energy (top panel) UV fluctuating around 1%, the middle energy UV around 0.5%, and the lowest energy UV flux (bottom panel) varies around 0.3%. More importantly, the lower energy UV rays, which clearly are the cause of the spikes-down in TSI/SSI during high solar activity.



The genesis of the TSI/SSI problem has thus been revealed to be the heavier weighting of longer-wave UV in climate models than those of higher energy, combined with the failure to examine space weather impacts on layers other than the upper atmosphere, as is the case with strong solar events. This misguided focus on upper-atmospheric heating is the genesis of the “solar constant”. Now, not only do we have a new dataset that shows alternative versions of the solar irradiance story, but we have the particle datasets too. While the longwave UV is most dominant in abundance, it never modulates at the threshold forcing level.

Some of the longer-term solar forcing pathways are understood and even becoming well-accepted, but few, if any, of the short-term forcing of significant weather patterns are accepted among most “global warming” scientists. One of the areas where acceptance is happening most quickly is in Asia, where the monsoonal patterns mean much more than a political and financial game- it’s life, and they just care about getting it right. The next image depicts a few of the known solar forcing pathways and implied timelines.

Image: Xiao et al. 2017



In the graphic above we find the long-term forcing pathways down the middle while the sides represent the potential for short-term forcing via particle (left and right) and wave (center) energy. While this study was a tremendous leap forward, it is only minimally inclusive of the body of available literature. Furthermore, whether you stick with the monsoon (bottom-line) or substitute for global temperatures, precipitation, cyclone activity, etc., we see connections directly to “Cloud Microphysics Process” and “Atmospheric Electric Field” without the need for large-scale oscillations and modes acting as intermediaries (Chapter 5).

In the wake of the release of the solar particle forcing dataset, we have seen no shortage of studies continuing to blame anthropogenic emissions for climate change, but they are not using CMIP6 solar particle forcing. However, many studies have used the new dataset to strengthen the known correlations between the sun and weather/climate, and to discover numerous others.

The standard story of “climate change is doom and it is all our fault!” is being refuted by top scientists at top U.S. national labs (Frank 2019), scientists presenting at the #1 geophysics conference in the world (AGU 2019), a team of geophysicists, paleo-climatologists and ecologists from China (Wu et al. 2019), another team from China and Australia (Yi et al 2019), confirming the work of an international team that includes NASA scientists and others from top universities around the world (Tsurutani et al. 2019; Tsurutani et al. 2016) … basically the hundreds of cited works in this book contain 1000s of climate scientists who have a different story to tell than what you hear on TV.

“But doesn’t that affect the 97% consensus number we’ve heard about? Don’t they all agree?” Solar climate forcing researchers have not been considered “real climate scientists”- they don’t get a vote.

Key Points:

1) Ego, funding and politics still present significant barriers to change in the realm of "climate science".

2) The UN IPCC (official global climate group) has written the sun out of their mandate and scope of investigation, has never re-examined the "solar constant", and this has provided the genesis of the world's misguided thinking on space weather and climate.

3) Top solar physicists have compiled and published a new set of solar data to be used for the next official climate model (Matthes et al. 2017).

4) The negative-reaction of TSI to increased solar activity is revealed to be based in the weaker wavelengths of ultraviolet energy, which is inexplicably weighted more heavily than the more-energetic waves, and in the TSI model focus on the upper atmosphere while ignoring Earth's other layers.

WARNING: For Students… and Anyone Who Can’t Help but Speak Their Mind

This book is a framework based on peer-reviewed science, diligent observation and analysis. Yet it still presents controversial ideas in a controversial topic, where politics and personal beliefs overshadow science at every turn.

If you are in a related class in school, or your friends and relatives are passionate about humans controlling everything that goes wrong on this planet (where we are out-weighed and out-eaten by ants), **then you must be especially careful about how you apply and discuss the material in Chapters 3-8**.

There is a time to do battle with an entrenched paradigm, and there is a time for patience. Your final exam, or mid-lecture in front of 100 other students, or thanksgiving dinner, or a first date… these are examples of times when you should avoid bringing up topics that might conflict with the others’ view of the world. This advice is especially critical if your class grade depends on it.

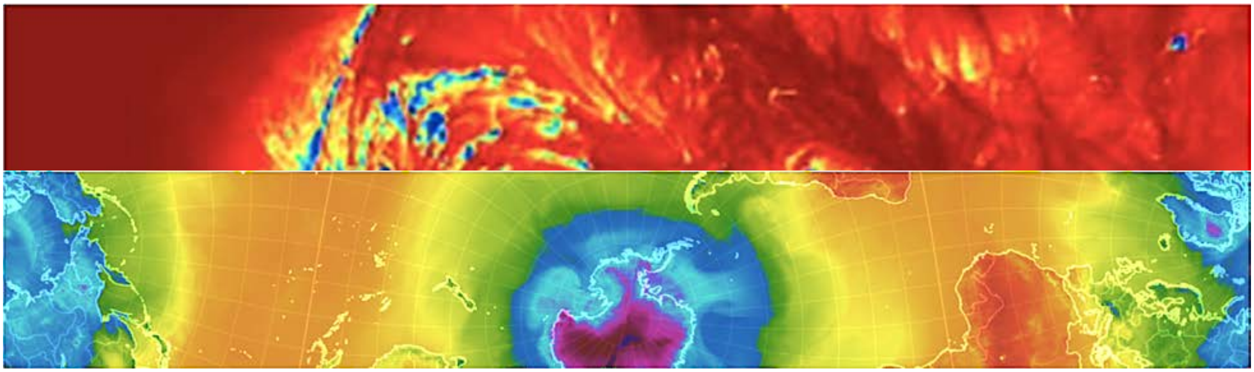
You don’t get points in school for being smarter or more knowledgeable than the teacher; the correct answers on the exams are based on what you have been taught, regardless of whether or not they are correct in the real world. **Family gatherings and first impressions should be about the people you are with**, not what needs to change in the world of science.

There is time and opportunity to change the world, but to get in the door you cannot be trying to set it on fire along the way.

4.0 Cycle and Pattern Modulation

We have reviewed some space weather basics, the history of solar climate forcing, as well as the status and possible missing pieces of climate science. Now we can begin to take a look at some of the studies that will be used as the foundation for driving this field forward. In this chapter, we look at some of the patterns, oscillations and key characteristics of Earth's weather and climate, and how they are modulated by space weather events and cycles.

A complete historically contextual review of the sun-Earth relationship would contain thousands of references, with paragraphs to pages of citations for every fact. Instead, we will focus on mostly the latest works, which paint a clear picture of space weather effects on the weather and climate, and the modern direction of the field. This will allow for a complete survey of the latest perspectives within the field, without the burden of its overwhelming totality.



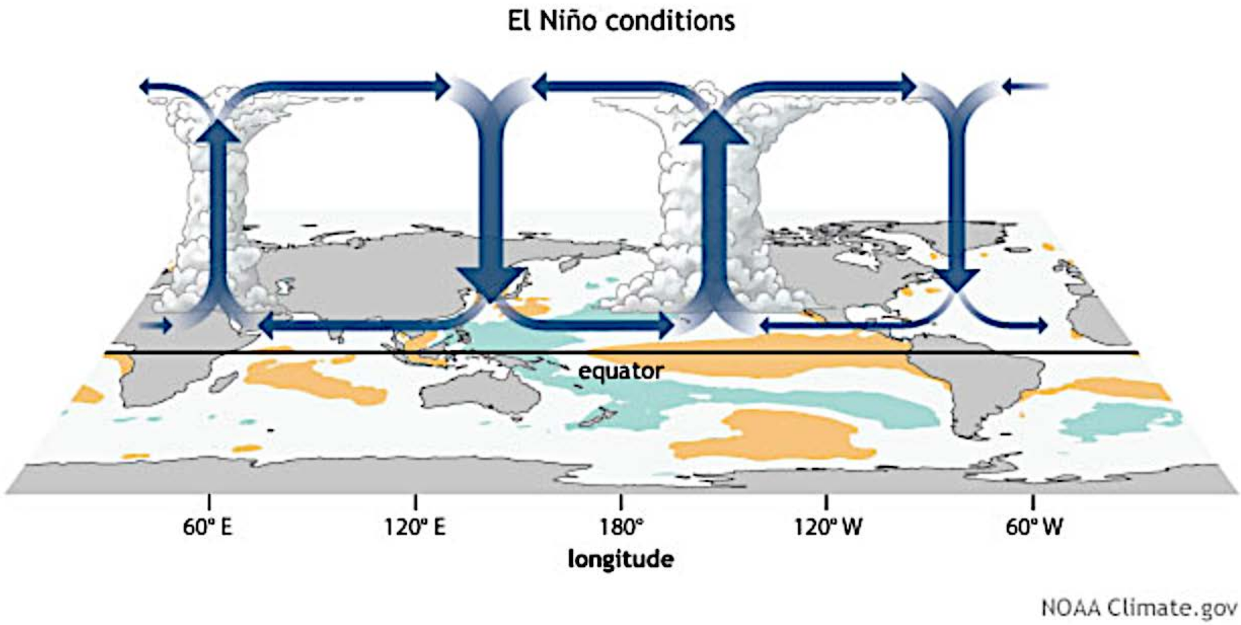
4.1 Major Oscillations and Circulation

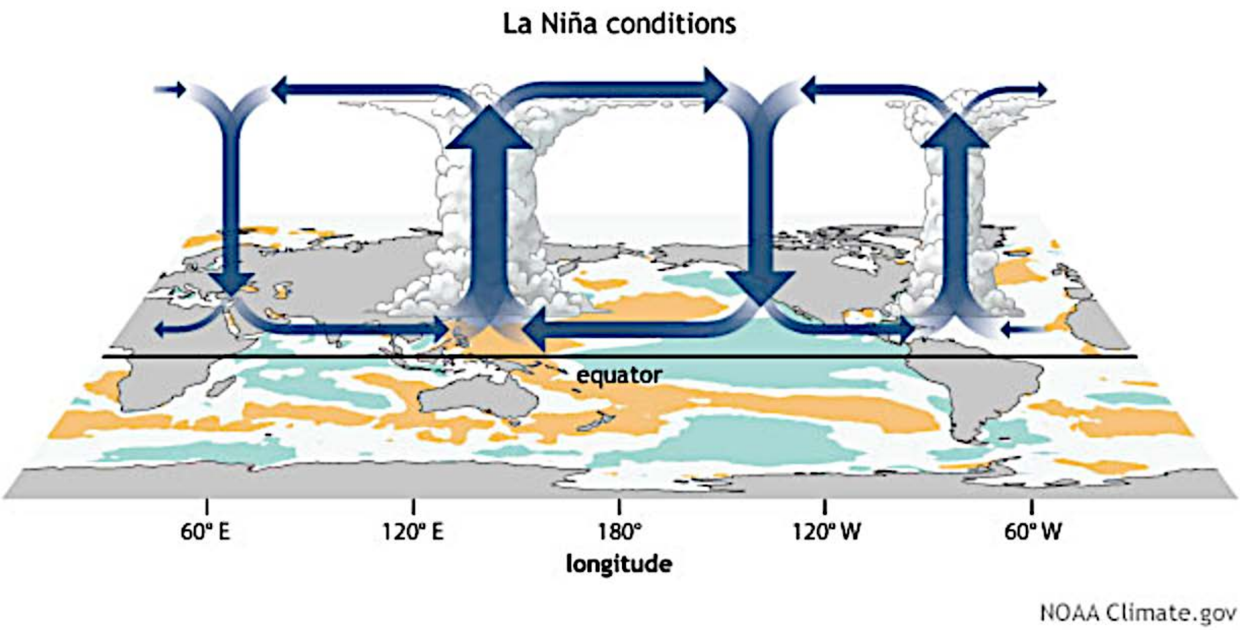
ENSO, AMO, PDO, NAO, QBO, SAM, NAM, AO - each is an acronym or initialization for a major atmospheric or oceanic oscillation. In this first section of Chapter 4, we will describe which large-scale oscillations and atmospheric dynamics are likely to be affected by the sun and space weather, along with some basic notes about the oscillations themselves.

4.1.1 El Niño/La Niña (*ENSO*)

ENSO is the most well-known of the major climate oscillations, the shifting between El Niño and La Niña. El Niño/La Niña refers to the warming/cooling cycle of the tropical Pacific Ocean sea surface temperatures. The extremes of the cycle, the strongest El Niños and La Niñas, increase extreme weather events worldwide, such as droughts, floods, heat extremes and winter storms. El Niño conditions result in the largest increases in global temperature, which occurred in 1998 and 2015/2016, with the strongest El Niños on record.

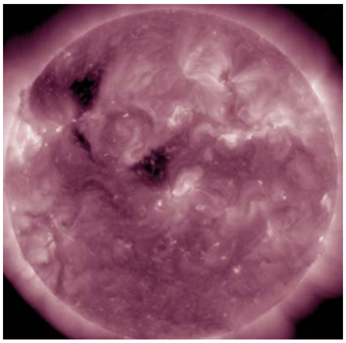
El Niño is usually seen along with high pressure in the tropical west Pacific, while La Niña comes with lower pressure. The following two images from Climate.gov show the difference between El Niño and La Niña conditions as a part of the Walker circulation, a turning-over of the atmosphere within the tropical region. The turnover pattern is always present, but where the heat is coming from and where it drives the downflows makes all the difference in regional weather.





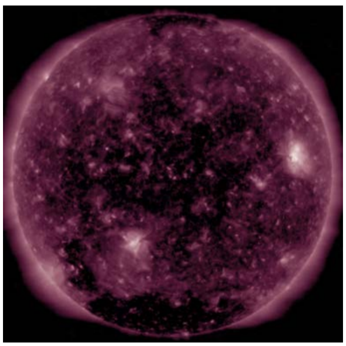
1) **What does the sun do?** Space weather directly modulates the ENSO cycle, with high solar activity driving positive ENSO (El Niño) conditions, and low solar activity forcing negative trends (La Niña). Studies implicate a solar influence on atmospheric dynamics of pressure, jets, and the Walker circulation in this forcing of ENSO. (Huang et al. 2019; Misios et al. 2019; Perez-Rivares et al. 2019; He et al. 2018; Hou and Xiao 2017; Hassan 2016; Rädel et al. 2016; Zhou 2013; Troshichev et al. 2005; Zhao 2003; Kirov and Georgieva 2002).

2) **When are the effects seen?** There have been correlations discovered between solar activity and ENSO at decadal (sunspot cycle) and interannual (1 - 4 years) forcing lags, meaning that the effects of the sun can be delayed through various atmospheric processes. (Wang et al. 2019; He et al. 2018; Hou and Xiao 2017).



Solar Maximum produces positive trends in ENSO

There is a 1 to 4-year lag time of solar forcing on trend of ENSO, and also longer-term trends reflecting overall sunspot cycle strength.



Solar Minimum produces negative trends in ENSO

3) **Expanded Impact:** The ENSO has connections to various other circulations and modes; therefore, any modulation of it has the potential to produce even broader effects than simply “El Niño vs. La Niña.” For example, the sun likely modulates how well the Pacific-North American weather patterns react to ENSO (Li and Xiao 2018) and therefore how precipitation falls over the United States and Canada; the ENSO is known to modulate numerous other oscillations and atmospheric modes by itself, providing further avenues for indirect forcing.

4) The action seen during and immediately following solar maximum is described as the unmistakable formation of a subtropical cyclone in the north-east Pacific, which confines the otherwise widespread cloud cover across the Aleutian Low and allows sunlight to heat the ocean. This heat travels directly to the tropical central Pacific and can vastly influence the ENSO-relevant water temperatures (Hou and Xiao 2017).

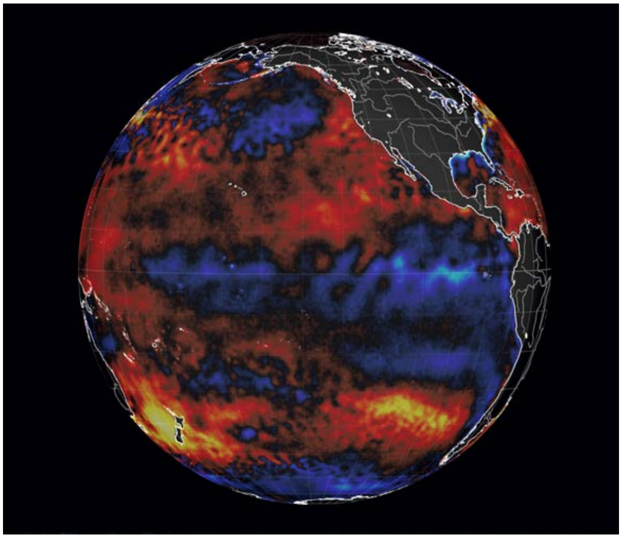
5) The hypothesis that high solar activity precedes El Niño is more than a decade old, and actually began with a correlation to the magnetic activity and IMF activity data of sunspot maximum (Troshichev et al. 2005).

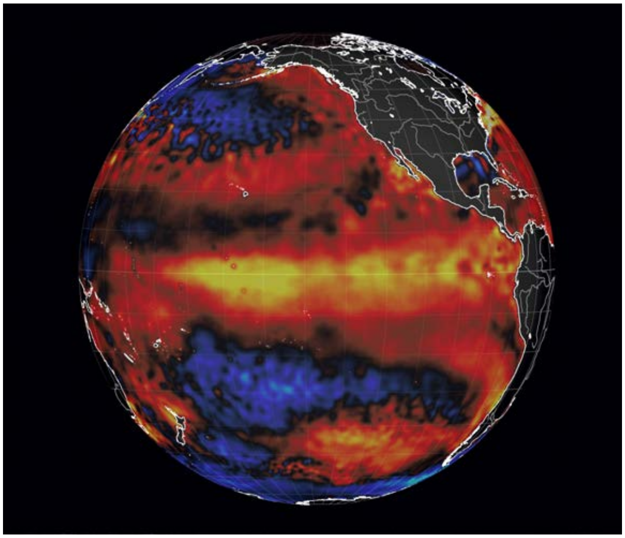
6) The solar modulation of ENSO has been shown to hold over centennial time scales (Wu et al. 2019).

Key Points:

1) Solar Forcing of ENSO Trend:

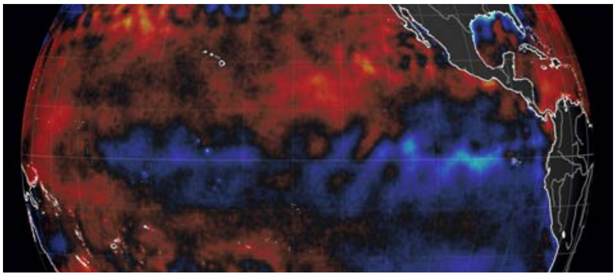
<u>Solar Minimum + ~1-4yrs Lag</u> **<u>Solar Maximum + ~1-4yrs Lag</u>**

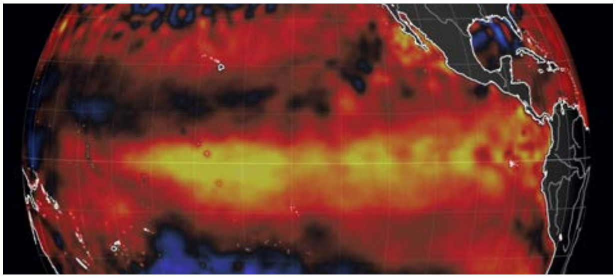




ENSO Negative - Cold Equatorial Water (Blue)

ENSO Positive - Hot Equatorial Water (Red, Yellow)



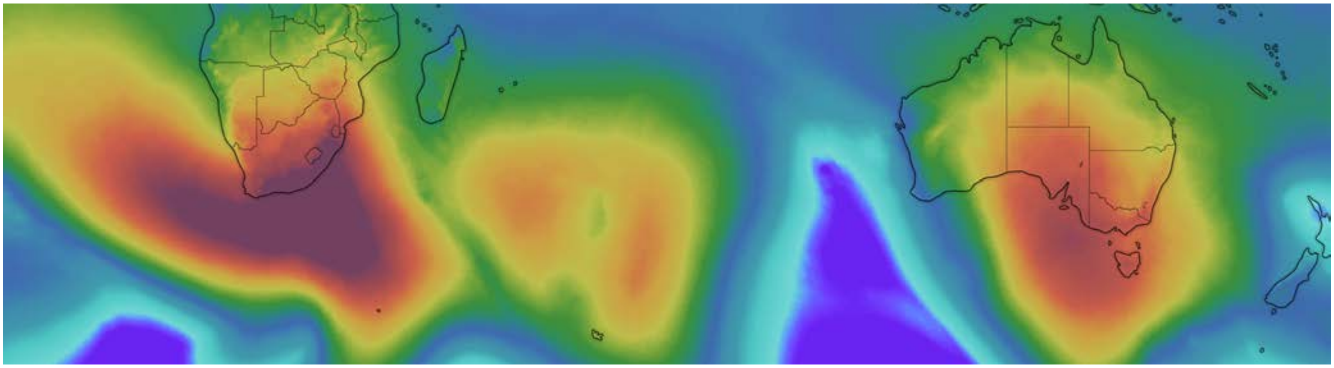


2) A key heating signal is delivered to global temperatures by high solar activity, through the ENSO positive phase (El Niño), which lags ~ 1 to 4 years after the high activity.

3) Since ENSO is known to modulate the entire world, and numerous other atmospheric oscillations and circulations, any effect on ENSO is likely to add an indirect solar forcing to many other aspects of weather and climate. These are in addition to the direct solar forcing of those modes and patterns, which are described in the following sections.

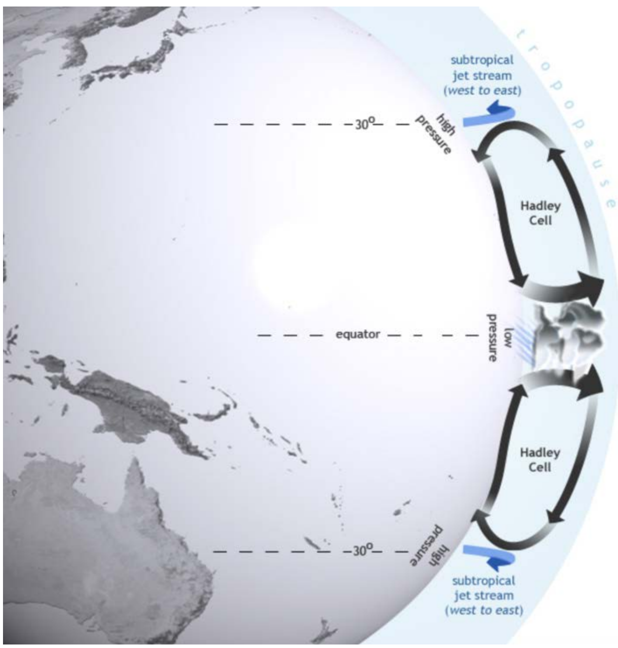
4.1.2 Atmospheric Pressure, Jets & Circulation

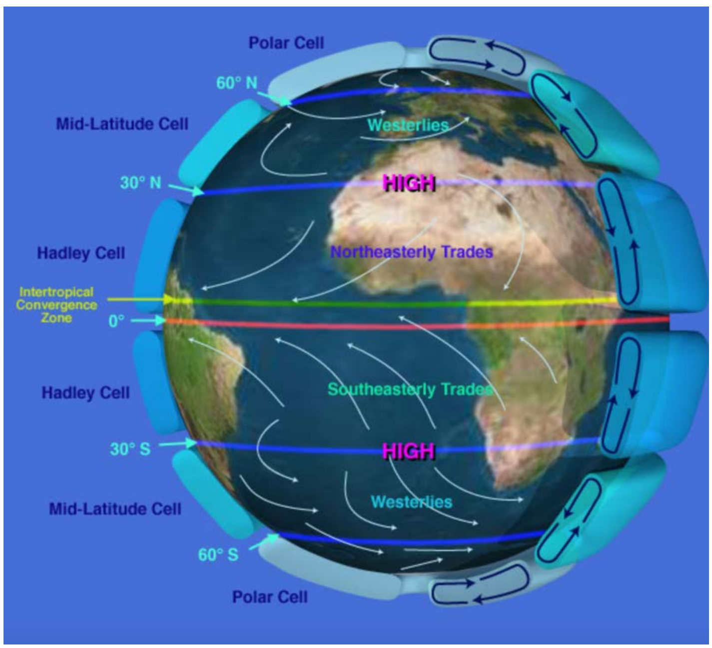
While the ENSO is a large-scale oscillation that modulates various cycles and climate phenomena, there are also other significant oscillations. Their solar-forced behavior all involve the action on large (State-Continent size) pockets of air or water, and on the upper atmospheric jets. This modulation goes well beyond the slow, top-down TSI heating model.



Pressure (Purple - Low, Red - High), Windy.com

The following images from NASA.gov show the equatorial air masses known as the Hadley cells, the mid-latitude cells, and the polar cells. The jet streams and polar vortices sit between these cells at approximately the 30 and 60 degrees latitude. The subtropical jets are labeled on the left, and all jets are shown as horizontal blue lines on the right. The Walker Circulation runs between the Hadley cells.





There are a number of studies indicating the sun's effect on the large pressure cells in the atmosphere, the Walker circulation and Hadley, mid-latitude and polar cells.

1) When the sun gets active:

a. Coronal mass ejection (CME) impact drives rapid surface pressure variation (Bucha 2019; Ma et al. 2018; Zhou et al. 2018; Lu et al. 2017; Prikryl et al. 2017; Gray et al. 2016; Artamonova and Veretenenko 2014; Bogdanov 2014; Gray et al. 2010).

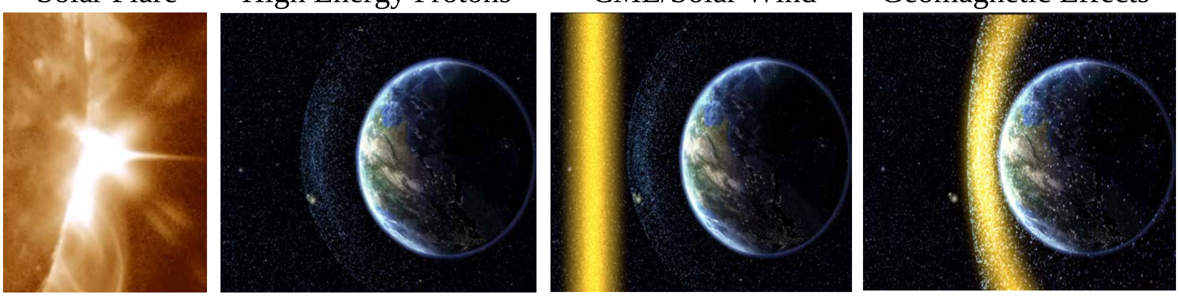
b. Solar flare modulation of pressure is seen more in lower latitudes, while cosmic ray modulation/CME impacts and the resulting geomagnetic activity appears to have a stronger effect at higher latitudes, especially on the semi-permanent pressure cells like the Icelandic low (Georgieva et al. 2007; Zaitseva et al. 2003).

c. Space weather variation has direct short-term large-scale effects on **centers of action** of pressure cells, major circulations and regional atmospheric dynamics (Maliniemi et al. 2019; Misios et al. 2019; Prikryl et al. 2019; Kretschmer 2018; Danladi and Akcer-On 2017; Yukimoto et al. 2017; Lu et al. 2017; Wang et al. 2016; Moffa-Sánchez et al. 2014; Zhou et al. 2014; Adolphi et al. 2014; Gray et al. 2013; Roy 2013; Wirth et al. 2013; Zhou 2013; Veretenenko and Ogurtsov 2012; Woollings et al. 2010; Tinsley et al. 2007; Haigh and Blackburn 2006; Kodera and Kuroda 2002; Kirov and Georgieva 2002; Tinsley 2000 and numerous others)

d. Modulation on centers of action (and also the modulation of clouds, precipitation, temperature, convection) is likely caused by the particle energy (solar wind, CMEs, SEP, GCR) directly influencing microphysical electrical activity in the atmosphere (Prikryl et al. 2019; Xiao et al. 2017).

e. At the polar cell, the interplanetary electric field appears to have a direct relationship to atmospheric pressure and wind vectors (Bucha 2019; Freeman and Lam, 2019; Mayewski et al. 2017; Lam and Tinsley 2016; Troshichev and Vovk 2004; Shirochkov and Makarova 1996) and to geopotential height anomalies (Lam et al. 2014).

	Solar Flare	High Energy Protons	CME/Solar Wind	Geomagnetic Effects



Effects:	Low Latitude (Walker/Hadley)	Polar Region (Polar Cell)	Entire Atmosphere (Stronger at Low Latitude)	Polar Region (Polar Cell)

The Walker circulation and Hadley cells intensify and expand towards the poles during high solar activity, while the polar cell response is an intensification and tightening, *without* expansion towards the equator.

2) Long-term modulations:

a. Various Arctic and Antarctic data sites have shown long-term surface pressure dependence on TSI (total solar irradiance), solar radio flux and sunspot numbers, as well as the interplanetary magnetic field, and solar wind events like coronal hole streams (Kanao 2019; Knisova et al. 2017; Lam et al. 2017; Mayewski et al. 2017; Regi et al, 2017; Burns et al. 2007; Troshichev et al. 2005).

b. Solar minima (11-year/400-year cycle) have been suggested to suppress the Aleutian low pressure cell and shift it eastward, and to enhance the Northern Pacific highs, which significantly modulates North American rainfall patterns (Patterson et al. 2013).

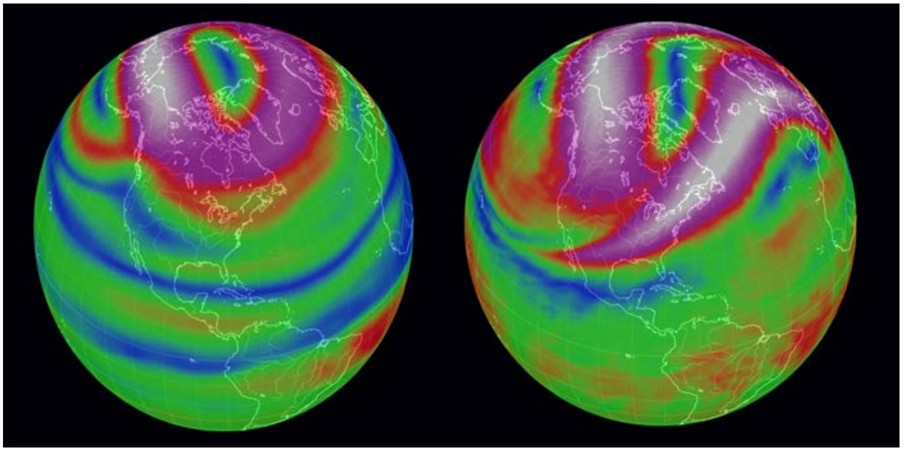
c. There is evidence of millennial-scale solar activity minima driving cooler temperatures over the northern continents via a southward shift in the intertropical convergence zone (ITCZ) (Moreira-Turcq 2014), which allows polar air to migrate southward and would have been accompanied by warming in the polar region and some equatorial confinement of tropical storm systems. This makes sense with the long-term lack of Hadley cell expansion that comes with such minima.

3) Polar Vortex Forcing:

What is the polar vortex and why does it matter for cold weather? In the next set of images, we see the northern polar vortex structure denoted by the white/purple segments near the Arctic. The circulation spins counterclockwise from this vantage point.

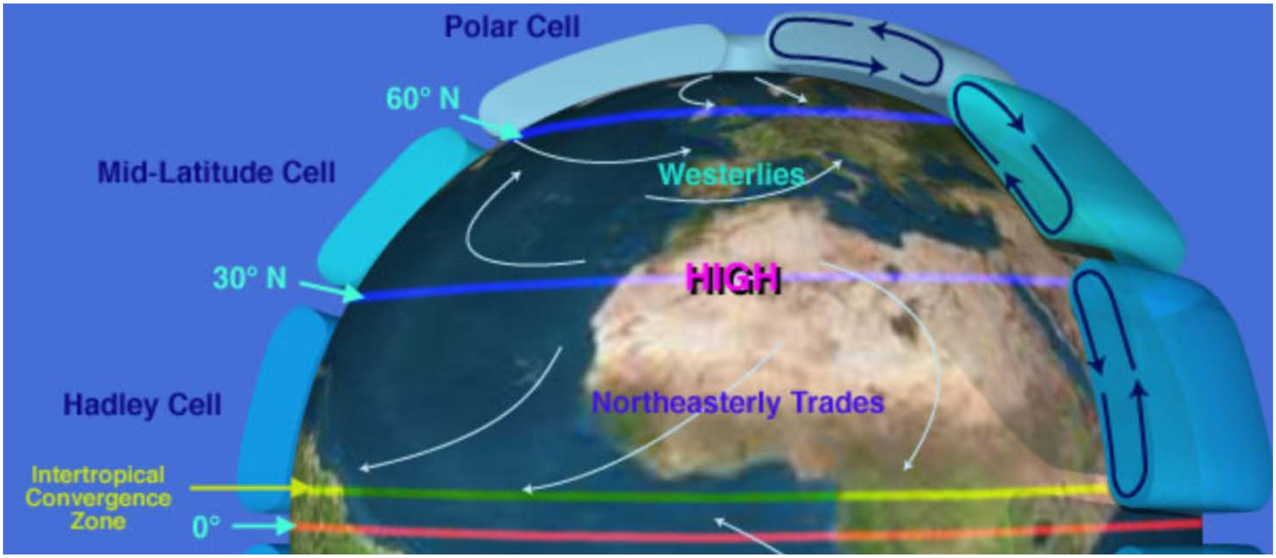
Image: Earth.nullschool.net

LEFT: Strong, tight (unbroken) polar vortex, which tends to hold the arctic air at high latitude, and results in fewer severe cold outbreaks in winter. RIGHT: Weak, disturbed polar vortex. In the scenario pictured here, the western USA and Canada should experience a cold wave.



a. Numerous studies corroborate the finding that solar minima result in worse winter polar vortex events, resulting in more cold events, or that solar maxima strengthen and tighten those vortices near the poles, resulting in fewer cold events. There are short-term and lagged effects of 1 - 4 years noted (Bucha 2019; He et al. 2019; Maliniemi et al. 2019; Salminen et al. 2019; Veretenenko and Ogurtsov 2019; Brahim et al. 2018; Kretschmer 2018; Ma et al. 2018; Lu et al. 2017; Yukimoto et al. 2017; building on the work of: Li and Tung 2014; Veretenenko and Ogurtsov 2014; Gray et al.2013; Lu et al. 2008, Claud et al. 2008).

b. Just like ENSO, the polar vortex phase is not equally acting on all parts of the world. Australia is the perfect example; the weak polar vortex causes warm and dry weather there as the usual precipitation wave train shifts away from its normal path (Lim et al. 2019).



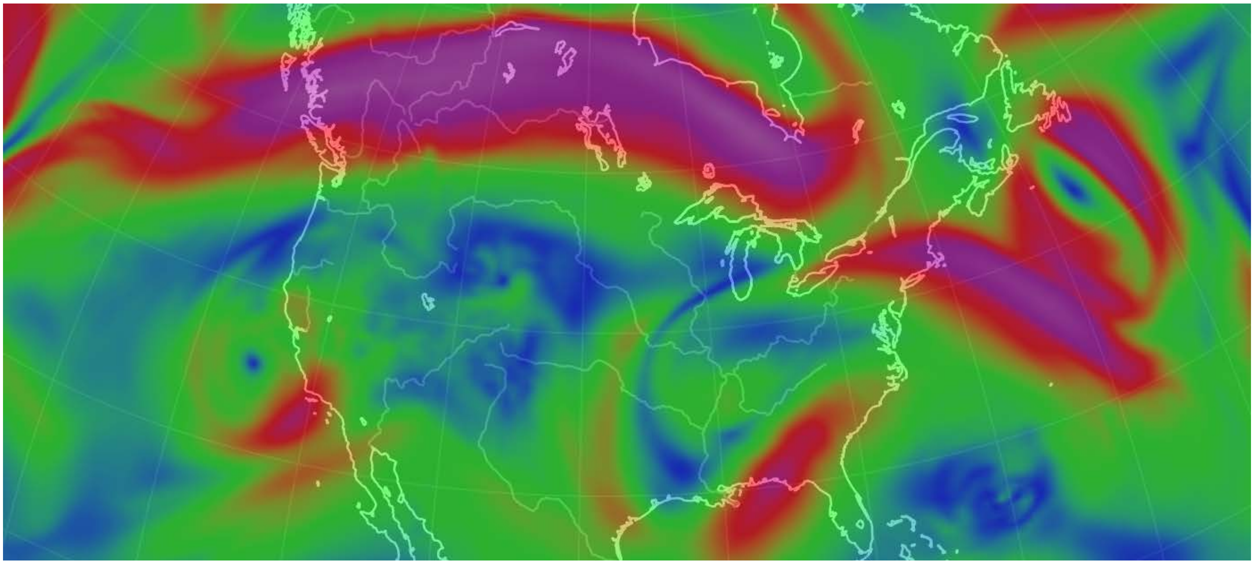
4) Jet stream forcing:

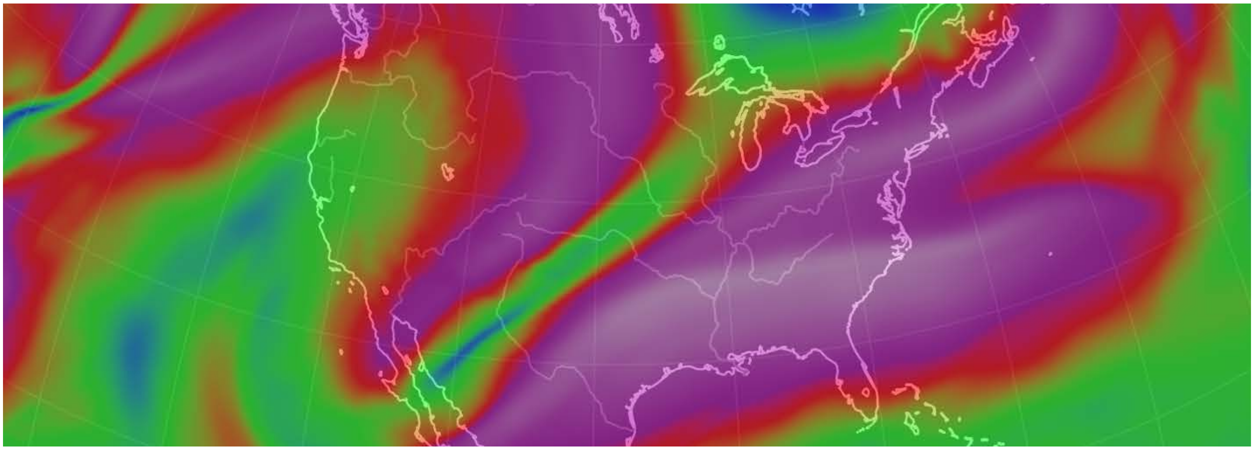
Recall that the jet streams ride between the larger atmospheric cells (Hadley, mid-latitude, polar):

a. Low solar activity leads to disruptions to subtropical jets and to the mean meridional circulation in the troposphere (Li et al. 2019[1]; Haigh and Blackburn 2006).

b. Jet stream blocking appears to be strongest during solar minima and can result in abnormal fluctuations of temperatures and enhancement of vertical temperature gradients (Li et al. 2019[1]; Ma et al. 2019; Ma et al. 2018; Gray et al. 2016; Adolphi et al. 2014; Moffa-Sánchez et al. 2014; among others).

c. Subtropical jets show a 10 m/s difference between solar maximum (faster) and solar minimum (Kodera and Kuroda 2002).





Earth.Nullschool.Net

In the images above, we see a strong, mostly-flat jet stream (top), and a weak jet stream blocking event (bottom) leading to larger temperature swings and precipitation anomalies. Solar maximum years in general force the top scenario, while solar minimum appears to favor jet stream blocking seen on the bottom.

5) Roadmap forward

While studying the large-scale atmosphere processes begins our understanding of solar-terrestrial coupling, smaller scale regional and local effects lead to a number of new avenues of discovery.

Geopotential height anomalies exhibit a strong relationship with solar and geomagnetic activity (Ma et al. 2019; Li and Xiao 2018; Bochníček et al. 2012, Thejll et al. 2003). The Siberian high intensity (SHI index) is directly correlated (positive relationship) with sunspot/geomagnetic activity (Chen et al. 2015 and references therein).

There is direct forcing of wind speed and wave height, and of turbulent energy at ground level, associated with high-speed solar wind (Lee et al. 2019; Wilhelm et al. 2019).

The jets, oscillations, circulation systems, and pressure cells control nearly everything that we experience in meteorology. Solar forcing of these dynamics is wholly outside the standard paradigm of 0.1% variation and the thermal trickle-down effect from the stratosphere, but these effects are real and should be accounted for.

This is where the new solar particle forcing dataset may make a large difference in the modeling. For the first time (2020s) these large oscillations, modes and circulations will have to be analyzed from a perspective of solar particle forcing, which is likely to result in the inclusion of much more "solar climate forcing" in future results. We have examined ENSO and the largest scale cells, circulations and jets- now we will get more specific.

Key Points:

1) Space weather directly affects the upper atmospheric jets, and directly and indirectly affects lower atmosphere Hadley cells, winds, and pressure, which are the pathways of forcing for ENSO and other large-scale oscillations.

2) Solar minimum is associated with weaker polar vortex, and more severe cold events and jet stream blocking.

3) Studies suggest both wave and particle energy, over long and short periods, play a role in modulation of the ENSO and large-scale atmospheric pressure dynamics.

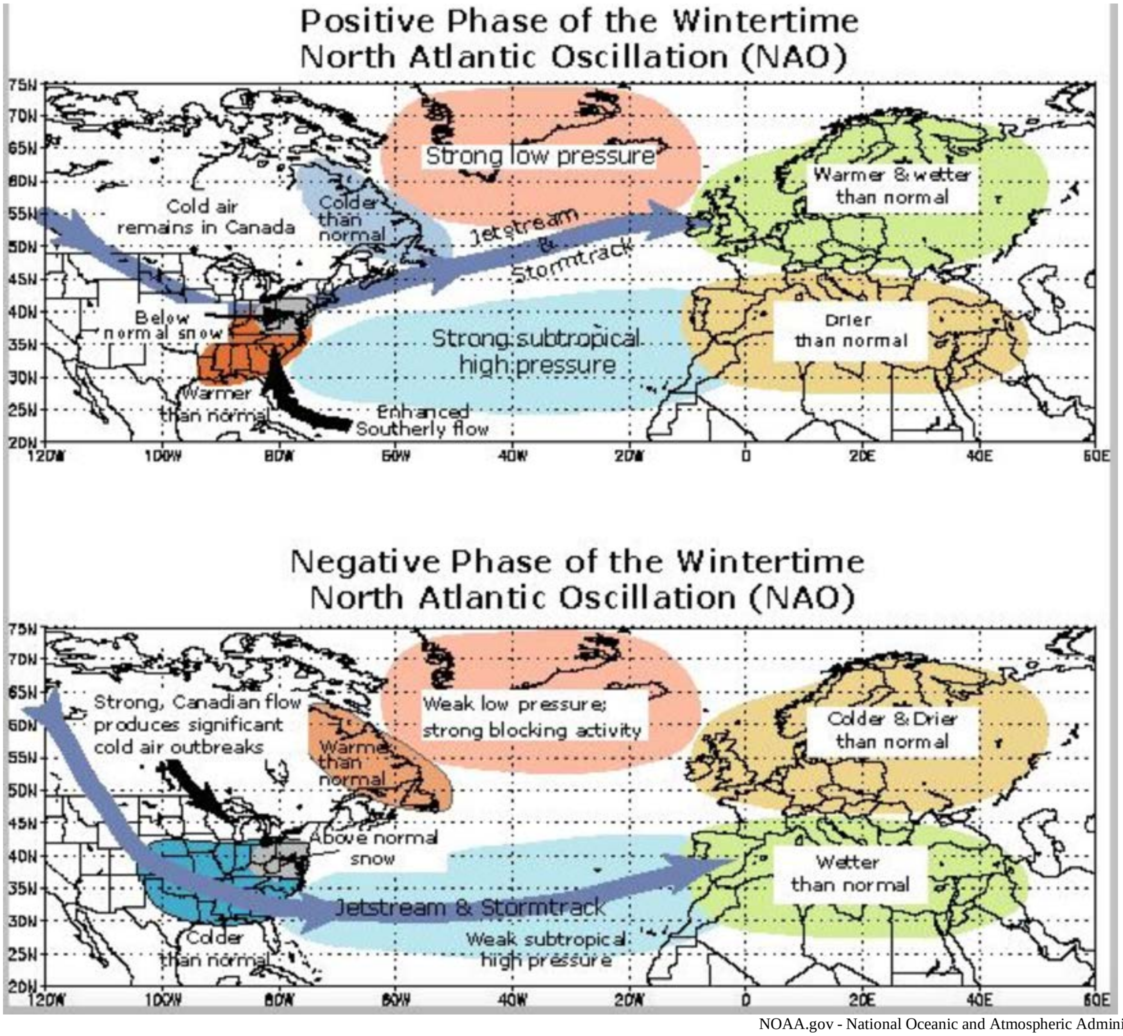
4) Strong solar activity expands the Hadley cell, and causes flatter/stronger jets streams.

5) Strong solar activity strengthens the polar vortex and tightens it near the poles.

4.1.3 Significant Oscillations other than ENSO

1) North Atlantic Oscillation *(NAO):*

While the ENSO is the most well-known climate oscillation, others have critical roles in determining the climate conditions across the world. In terms of the eastern United States, Europe, northern Africa and Russia, the positive and negative phases of the North Atlantic Oscillation (NAO) are by far the most important. Below is a graphic from the National Oceanic and Atmospheric Administration (NOAA) describing the stark differences between those phases.



NOAA.gov - National Oceanic and Atmospheric Administration

Notice how the precipitation increases in northern Europe in positive phase, while the USA has less snow. Colder temperatures find both northern Europe and the Eastern United States during the negative phase. If you have ever heard of the periodic “Greening of the Sahara”- it likely requires a persistent negative NAO phase. On the next page are some critical studies on space weather and NAO, and their results:

a. On both day-to-day and annual time scales, solar activity has a direct effect on NAO, with high solar activity causing positive trends in NAO phase, and low solar activity causing negative trends (Bucha 2019; Chen et al. 2019[1]; Gruzdev et al. 2019; He et al, 2019; Maliniemi et al. 2019; Perez-Rivares et al. 2019; Zhu et al. 2019 [2]; Lu et al. 2017; Gray et al. 2016; Wahab et al. 2016; Hou et al. 2014; Mazzarella and Scafetta 2011; Swingedouw et al. 2011; Woollings et al. 2010; Gimeno et al. 2003).

b. Powerful solar flares (M/X class) tend to create temporary (~9 days) positive forcing of the NAO phase driven indirectly by forcing of lower Icelandic low pressure and higher Azores pressure. (Georgieva et al. 2007).

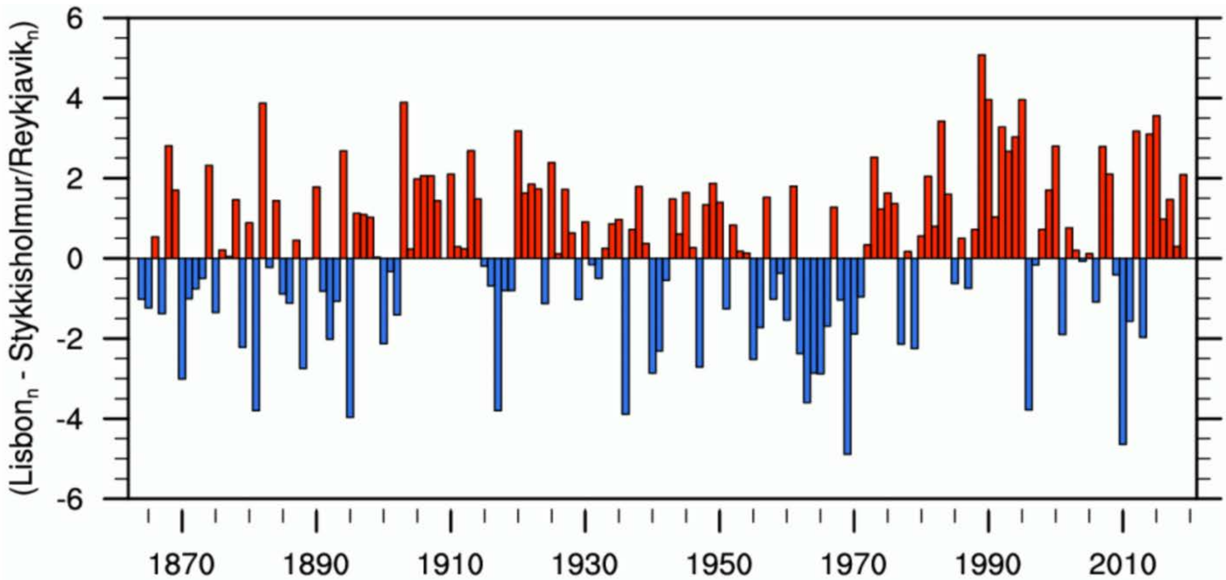
c. Over longer time periods (multi-decadal/centennial), the correlations between solar activity and both NAO and ENSO have been shown to have a very close relationship (Gruzdev and Bezverkhnii 2019; Ait Brahim et al. 2018; Kirov and Georgieva 2002).

d. Short-term and long-term effects on the NAO index result from electric field changes propagated downward by impacting solar wind and solar flare heating of the upper atmosphere (Perez-Rivares et al. 2019; Zhu et al. 2019 [2]; Wahab et al. 2016; Hall et al. 2016; Thiéblemont et al. 2015; Scaife et al. 2013; Gray et al. 2013; Bochníček and Hejda 2005; Zaitseva et al. 2003; Boberg and Lundstedt 2002; among others).

e. The correlations between solar activity and NAO have been shown most strongly with the effects lagging a few years behind solar activity (Maliniemi et al. 2019; Ma et al. 2018; Scaife et al. 2013) with positive NAO phase appearing strongly a few years after solar maximum (Thiéblemont et al. 2015; Maliniemi et al. 2014; Gray et al. 2013). While most of the literature suggests a 1 to 4-year lag time, a complimentary (additional) strong 7-year lag signal was recently identified following the sunspot cycle (Gruzdev and Bezverkhnii 2019).

Important Note: Geomagnetic peaks in the ~11-year solar cycle tend to lag the sunspot maximum by one to three years, so perhaps a more direct correlation, with less lag, could be constrained by focusing on the solar wind or geomagnetic effects rather than the solar flares or sunspots. In other words, when a forcing modulation is showing a 3-year lag with solar irradiance or sunspots, this may have virtually no lag at all with geomagnetic effects and high-speed coronal hole streams. This sort of oversight was more common in earlier works and is becoming rare in the new era of "solar particle forcing".

The appearance of sunspots does not necessarily indicate that geoeffective space weather will occur (solar flare or CME impact needed); monitoring the geomagnetic effects is better than monitoring sunspots in yet another way.



NAO Index 1864-2019, University Corporation for Atmospheric Research

The majority of short-term effects and a significant portion of the longer-term effects noted here are the result of solar wind fluctuations, heliospheric and interplanetary magnetic field changes, solar flares, and galactic cosmic rays (GCR) at Earth, which all fluctuate much more over those short timescales than do sunspots. Roy et al. 2016 demonstrated that the lagging geomagnetic peaks are actually better measures of solar forcing on winter surface climate than sunspot numbers, which supports this idea of focusing on short-term space weather rather than an 11-year cycle.

Some scientists have suggested that the extent of solar forcing on the NAO depends on whether the oscillation is in phase with radio flux variation, with positive NAO anomalies stronger in phase with peaks and negative NAO anomalies when out of phase (Van Loon 2014; Van Loon and Meehl 2013). It could be argued that because high solar activity offers regular opportunities for phase alignment, while periods of grand solar minima offer far fewer (if any) opportunities for phase alignment, grand solar minimum should favor the negative phase of the NAO regardless.

The negative phase forcing of low solar activity/high GCR is the most well-documented of the solar NAO forcing, which has the practical effect of directly modulating the severity of winter storms along with polar vortex modulation. The variations in these oscillations tend to be the result of changes in the centers of action of pressure cells and other atmospheric dynamics, as discussed in the previous section.

In the first decade of this millennium, scientists began to argue that an additional NAO-forcing mechanism at work is the result of solar activity affecting the global electric circuit (Tinsley et al. 2007; Bochníček and Hejda 2005; Tinsley 2000 among others); this mechanism will be detailed in Chapter 5, and is likely correct. It is an important hypothesis because the solar forcing significance implies a coupling level beyond what has been modeled in the past, and the global electric circuit provides that pathway for reconciliation.

2) Northern and Southern Annular Modes (*NAM* and *SAM*):

NAM and SAM are dynamic cycles of atmospheric activity at mid-latitude in the north and south respectively. **Nothing explains atmospheric activity outside the tropics as much as the annular modes on timescales from days to years.** While the NAM and SAM are strongly related to NAO and Southern Oscillation Index (SOI; this is the "SO" in ENSO), respectively, the NAM and SAM are separate indices, and are not actually "oscillations". The widespread influence of these patterns on the global atmosphere include strong influences over pressure near the polar regions, as well as land and ocean temperature at mid-latitude.

NAM and NOA phase values indicate largely similar patterns in the climate. On short timescales, NAM positive phase anomalies due to high speed solar wind streams lag only slightly longer (days) than the NAO and are most strongly seen near the surface (Georgieva et al. 2007). Similar high solar/geomagnetic activity forcing of positive NAM anomalies were reported in Roy et al. 2016 and Ruzmaikin 2007, and for charged particle precipitation in Maliniemi et al. 2016.

Positive SAM patterns lead to fewer cold events for southern hemisphere locations like Australia, and those positive patterns appear more often during solar maximum (Petrick et al. 2012 and the references therein). Meanwhile, the solar minimum effect is more to the negative phase (more cold events), is confined to the troposphere, and disappears much more quickly than the observed modulation of solar maximum (Kuroda and Yamazaki 2010).

Like ENSO and NAO, high solar activity drives positive phase trends in NAM and SAM, with low solar activity driving negative trends.

3) Pacific Decadal Oscillation (*PDO*):

PDO is a long-term, broader-scale version of ENSO. During a positive phase, we get warm east Pacific water and cooler west Pacific waters, which help modulate ENSO. PDO phase and trends show periodicities known to be driven by solar activity, including the 11 and 5.5-year variabilities (Le Mouel et al. 2019).

Higher solar activity leads to positive trends of the PDO, while low solar activity leads to negative trends (Maruyama and Morimoto 2017; Velasco and Mendoza 2008).

The influence of solar forcing on the PDO in the Gulf of Alaska may depend on phase matching with the 11-year sunspot cycle, in which high pressure anomalies are more confined to the Gulf when in-phase, and can spread more to the south and west when the cycles are out of phase (van Loon and Meehl 2013).

This strengthens the argument for solar forcing of ENSO through Pacific cloud distribution and surface pressure, as these would have similar PDO effects as well, and there is significant interplay between PDO and ENSO.

4) Atlantic Multidecadal Oscillation (*AMO*):

AMO is a sea surface temperature variation similar to PDO, except this one is in the Atlantic. Solar and volcanic forcing demonstrate excellent correlations with the AMO, but those disappeared during the Little Ice Age, when many oscillations were not as they are today. This may also be related to the ultra-low solar activity during that period (Knudsen et al. 2014).

The AMO has been long-known to have ~11-year cycle modulation (Velasco and Mendoza 2008). Recent studies have confirmed the relationship between AMO and the sun (Murphy et al. 2017; Wang et al. 2017), including 11-year cycle forcing, by focusing on the full breadth of high solar activity particle influence (Le Mouel et al 2019).

The PDO and the AMO are extremely important for global temperatures, so any modulating factor not currently included in their modeling will harm the accuracy of forecasting and analysis. Solar forcing of these different oscillations and modes has never been included in IPCC official modeling/analysis of ENSO, PDO, AMO, NAO, NAM, SAM… or QBO.

5) Quasi-Biennial Oscillation *(QBO):*

The QBO is a high-altitude jet over low- and mid-latitudes that is consistent in flow nearly all the way across the planet. It reverses every few years in an east/west oscillation. It presents one of the best examples of why solar activity has been overlooked in the past. Here are some of the relevant studies:

a. Using sunspot cycles, it is difficult to find a correlation between solar activity and high-latitude stratospheric temperatures; however, when the east vs. west phase of the QBO is accounted for, there are many evident relationships in the stratosphere *and* the troposphere (Labitzke and Van Loon 1988) that cannot be seen without that separation.

b. In addition to the QBO effect on solar modulation, the sun modulates QBO itself: Solar maximum tends to decrease the effects of the QBO, and solar minimum enhances the signal. It has also been suggested that the aforementioned phase-dependent modulation of solar forcing is confined to the northern hemisphere, whereas the solar signal is amplified by comparison in the southern troposphere, and that solar activity generally modulates the strength of the QBO (Petrick et al. 2012; Lu and Jarvis 2011; Gabis and Troshichev 2004).

c. Recently, a 3 to 4-year periodicity in atmospheric parameters relating to QBO and similar solar variability harmonics was discovered (Knizova et al. 2017).

** New studies are beginning to explore the connection between the Madden-Julian oscillation (MJO) and solar activity, with phase cycling tied to rotational cycles of the sun (Hoffman and Savigny 2019; Le Mouel et al. 2019). However, this author has reason to suspect that the 27 to 28-day weather correlations attributed to solar rotation (~27 days) are at least partially attributable to the 28-day lunar cycle. Caution is advised in assigning forcing numbers in such correlations. Considerable future work must be performed before any measure of certainty (or even a reliable hypothesis) may be made differentiating the forcings of the solar rotation and moon in the 27 to 28-day range. The most promising avenue here would be the 27 to 28-day recurrence of long-lasting active regions and coronal holes which persist for multiple solar rotations.

Key Points:

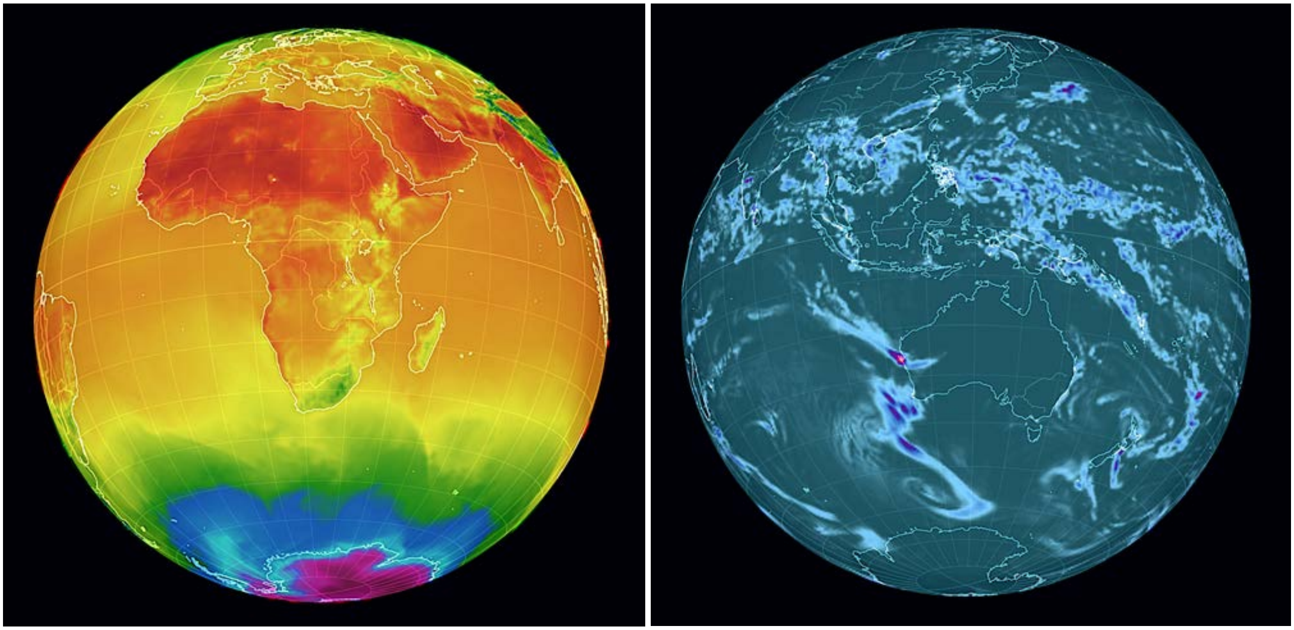
1) Solar activity is directly correlated (direct relationship) with NAO, NAM, SAM, PDO, AMO. High solar activity drives positive trends, low solar activity drives negative trends.

2) Solar minima modulation of these oscillations and modes help drive more cold extremes in winter, especially with the NAO and SAM.

3) The QBO strongly enhances or tempers solar forcing pathways based on the region and QBO phase, helping to explain patterns of stronger and weaker solar signals in major oscillations, jets, etc.

4) The strongest solar activity can induce significant short-term positive phase trends in atmospheric oscillations while adding energy to annual or decadal forcing trends at the same time.

5) The solar effect on the PDO is one of the primary means by which the sun modulates ENSO.



Earth.Nullschool.Net

4.2 Temperature and Precipitation

Here is something that none of the “97% of the climate scientists” who are certain about global warming have ever considered:

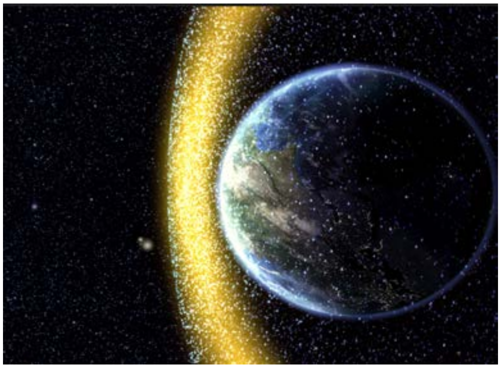
It is estimated that solar activity during the grand solar maximum of ~1940-2005 produced twice the number of CMEs as solar cycles just 100 years ago (Richardson et al. 2002). After high CME activity continued through 2005, the 2012-2015 activity maximum dropped to producing those early-1900s lower CME numbers. Particle forcing is not only missing from models, but it was doubly present during the latter half of the 20th century.

Much of the short-term forcing is missing from current models when the focus is placed on longer-term TSI, or even sunspot number, but is likely more evident in the solar-magnetic, geomagnetic, and cosmic ray modulations directly related to CMEs. Particle forcing is the only way to account for the temperature and precipitation correlations described in the literature.

1) Big Picture

a. Many studies have attributed changing global temperatures in recent decades, and in the past, to changes in solar and geomagnetic activity (Frederick et al. 2019; Freeman and Lam 2019; Maliniemi et al. 2019; Audu et al. 2017; Kitaba et al. 2017; Sukhodolov et al. 2017; Airapetian et al. 2016; Tiwari et al. 2016; Kodera et al. 2016; Spiegl et al. 2016; Aslam and Badruddin 2014; Biktash 2014; Stauning 2014; Avakyan 2013; de Jager and Nieuwenhuijzen 2013; Burn and Palmer 2013; Gupta et al. 2013; Sirocko et al. 2012; Courtillot et al. 2007 among others).

b. Rapid surface temperature fluctuations have been recorded during CME impacts, IMF changes, and high-speed solar wind streams, indicating **simultaneous** changes in both near-Earth space and the lower troposphere (Frederick et al. 2019; Freeman and Lam 2019; Frederick and Tinsley 2018; Kumar et al. 2017; Lam et al. 2017; Mayewski et al. 2017; Regi et al. 2017; Harrison et al. 2013; Seppälä et al. 2009, Troshichev and Vovk 2004, Shirochkov and Makarova 1996).



c. A strong bi-decadal (20-22 years) oscillation of global temperatures and humidity near the tropopause has been tied to the solar magnetic fields, which help modulate the galactic cosmic rays' influence on near-tropopause ozone (Wang et al. 2016; Kilifarska 2015).

d. Numerous studies have identified a general top-down (stratosphere to troposphere) modulation of global temperatures by the sun, acting in concert with anthropogenic and volcanic forcing (Mendoza et al. 2019; Audu et al. 2017; Kodera et al. 2016; Spiegl et al. 2016; Adolphi et al. 2014; Maliniemi et al. 2014; Liu et al. 2014; Chen et al. 2013; Powell Jr. and Xu 2012; Barnhart and Eichinger 2011; Miyahara et al. 2008; Claud et al. 2008 among others).

Note: These studies used the general 0.1% irradiance variation but were still able to make the argument that it was enough to "hit a threshold" of forcing that could noticeably affect temperatures.

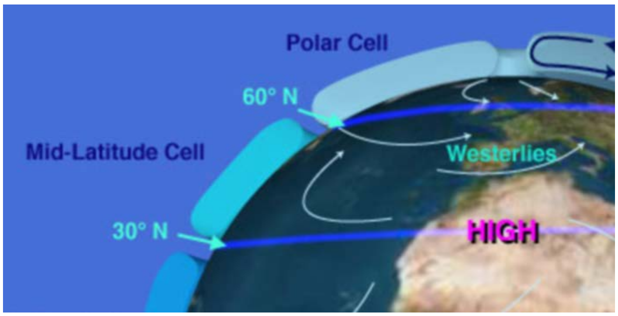
e. Solar maximum appears to bring warmer temperatures in the northern hemisphere, even when accounting for major oscillations such as the NAM, ENSO, and QBO (Frederick et al. 2019; He et al. 2019; Mendoza et al. 2019; Danladi and Akcer-On 2017; Zharkova et al. 2017; Claud et al. 2008; Usoskin et al. 2005; Gimeno et al. 2003).

f. The northern hemisphere correlation is evident on centennial timescales (Ogurtsov et al. 2015) but is seen most clearly in the declining phase of the sunspot cycle (Maliniemi et al. 2014), which makes the geomagnetic activity maximum (which is 1 - 3 years after sunspot maximum) the best indicator, with either a smaller potential lag or no lag at all.

g. Solar minimum can also bring warmer temperatures to some parts of the globe, specifically to northwestern North America, with warmer and drier conditions in the Pacific Northwest, the Canadian prairies, and the Ohio-Tennessee-lower Mississippi River Valley, which are exactly the expected results from the known solar-forced phases of NAO, PDO, and the Aleutian low (Liu et al. 2014). In these cases where forcing is opposite of expected for the rest of the world, we almost exclusively find that the oscillation phase forcing is responsible for the correlation (long-term thermal coupling), rather than a direct effect on the ground temperature. These are the areas that react oppositely to the major oscillations already.

2) Specific Forcings

a. Solar minimum (and grand solar minimum) intensification of "severe winter" in Europe is well documented (Frederick et al. 2019; Ma et al. 2019; Maliniemi et al. 2019; Gray et al. 2016; Hall et al. 2016; Spiegl et al. 2016; Adolphi et al. 2014; Moffa-Sánchez et al. 2014; Todorović and Vujović 2014; van Loon 2014; Gray et al. 2013; Sirocko et al. 2012; Lockwood et al. 2011; Lockwood et al. 2010; Woollings et al. 2010).



We can immediately apply what we have learned to understand why low solar activity intensifies severe winters in Europe. The Hadley/Mid-latitude Cells are weak and deflated, causing the jet stream to block and wobble, bringing more severe precipitation and temperature shifts (which make for freezing rain/ice storms in winter). The polar vortex weakening events also increase in frequency and severity, driving Arctic air intrusions into the lower latitudes. Finally, NAO negative forcing (from solar minimum) means cooler temperatures in wintertime for Europe in general. A quiet sun is the perfect storm for wintertime in Europe.

b. Decadal modulation of temperatures is evident in Romania, and in century-scale temperature variations in Fennoscandia and Portugal, having been correlated using sunspot numbers and cosmogenic isotopes (Moreno et al. 2019; Sfica et al. 2018; Ogurtsov et al. 2013).

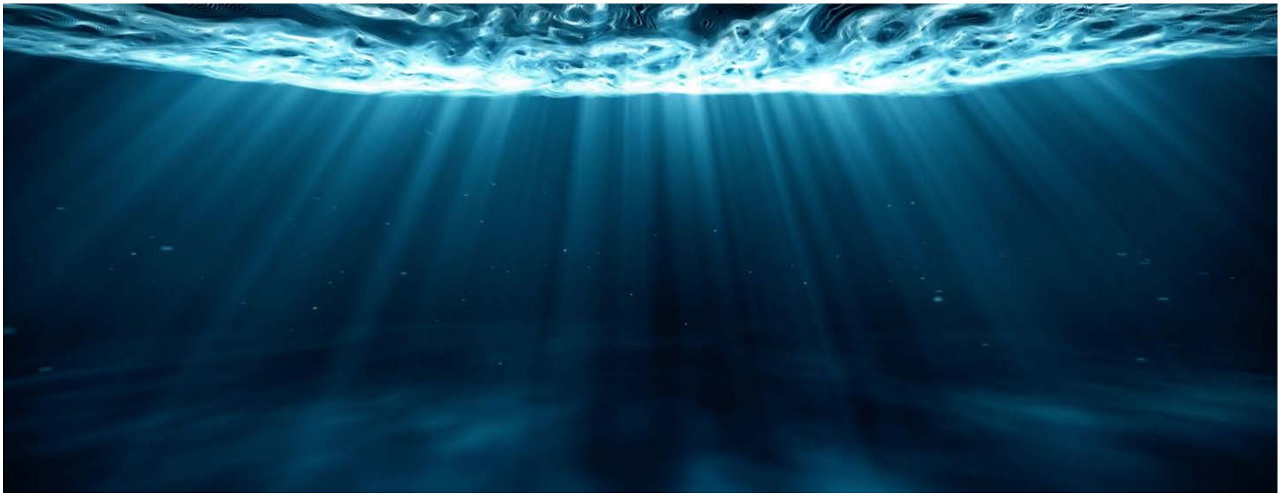
c. Powell Jr. and Xu (2012) and Mayewski et al. (2017) found direct-relationship solar cycle forcing on polar surface temperatures in winter. This is directly related to the polar vortex studies and solar wind coupling studies that found the same results (Frederick et al. 2019; Kretschmer 2018; Lam et al. 2018; Ma et al. 2018; Lu et al. 2017; Sukhodolov et al. 2017; Yukimoto et al. 2017).

d. Decadal to millennial periodicities in Asian temperatures have been described from China, Korea, India and Tibet (He et al. 2019; Yang et al. 2019 [1]; Sunkara and Tiwari 2016; Tiwari et al. 2016; Duan and Zhang 2014).

e. Short-term temperature data in India shows strong correlations with solar activity (Aslam and Badruddin 2014; Maitra et al. 2014).

f. In the tropics, solar maximum presents strong cyclical forcing on lower tropospheric temperatures, lagging about one week behind TSI (wave energy) peaks (Hood 2016).

g. Nigerian temperatures have shown periodicities related to the 11-, 22-, and 44-year solar cycles, which significantly match external forcing cycles from the sun, and which appear to become increasingly variable with greater variability in sunspot number (Audu et al. 2017; Okeke and Audu 2017).



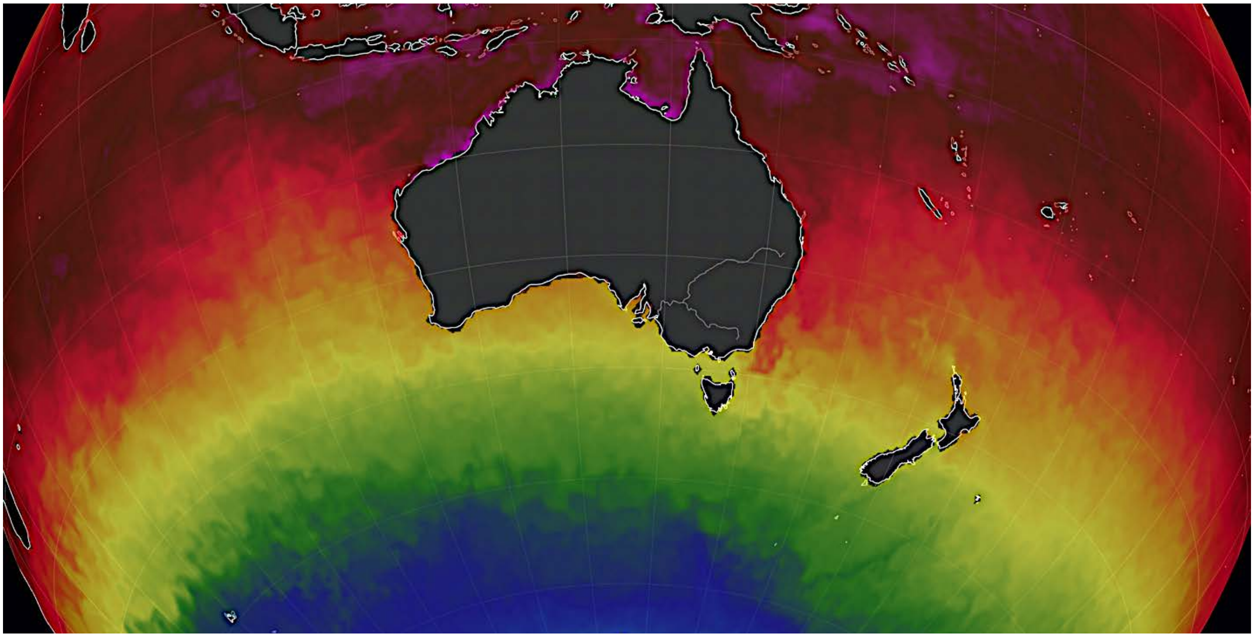
There is a legitimate question as to why some solar modulations (especially of temperatures) are rapid while others follow long period cycles or have lagged-forcing of years or more. Luckily, the answer begins relatively simply; the image above tells you a lot of what you need to know.

You must descend more than 600 feet into the ocean to reach a region where sunlight cannot penetrate and the sea turns to blackness; every molecule of water *above* that is bombarded with photon energy by the sun, which it transforms into heat energy.

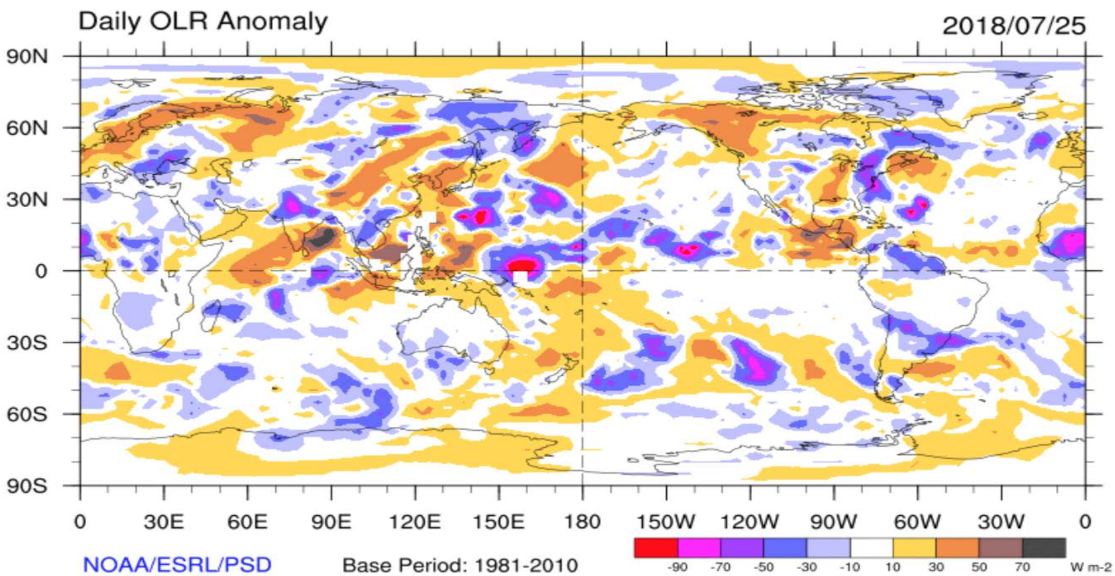
This energy can be lost in the water for decades, and that is just the light- we have not yet begun to address the particle or induction energy transfer into the ocean.

Speaking of which…

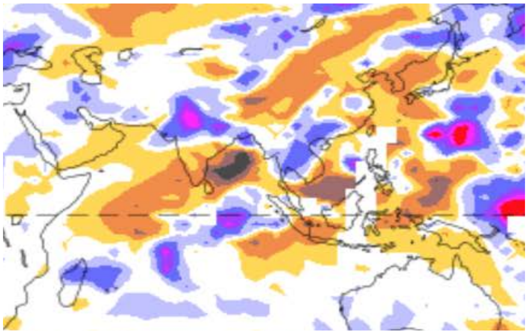
3) Ocean Temperatures



The global and regional oceanic temperatures also show strong correlations with solar activity; for example, solar influence on atmospheric circulation modulates surface air temperatures by controlling the position of deep convection and heat release, known as Outgoing Longwave Radiation (OLR), from the surface (Frederick et al. 2019; Hoffman and Savigny 2019; Xiao et al. 2016), which determines the heat exchange of the lower atmosphere. The image below shows the anomalies in OLR over 1 day. Anywhere cloudy will be slightly more negative, whereas clear-sky regions will be slightly positive.



The strong anomalies, close together, often indicate that the strongest pressure/wind/storms on Earth are nearby- these are like “delta class OLR anomalies” in the same way that delta class sunspots have the strongest flare activity!



We have already learned of numerous forcing pathways that could influence sea-surface temperatures (SST), such as:

a) a reinforcement of the wintertime NAO cycle (Gray et al. 2016),

b) modulation of the Atlantic meridional overturning circulation (Moffa-Sánchez et al. 2014),

c) modulation of the Atlantic multidecadal oscillation (Knudsen et al. 2014),

d) modulation of surface air temperatures in the stratosphere (Xiao et al. 2016),

e) and modulation of wind speed and wave height (Wilhelm et al. 2019).

Few aspects of recent research have exceeded the critical importance of the recognition that particle and geomagnetic forcing have provided further pathways for solar forcing of ocean temperature.

Evidence exists of SST correlation with solar wind events and resulting geomagnetic activity, sunspot number (as a proxy for solar wind/CMEs/high-energy protons), cosmic ray reconstructions from ice-core data, as well as total solar irradiance and related irradiance indices (Zherebtsov et al. 2019; Xiao et al. 2017; Xiao et al. 2016; Zhou et al. 2016 [1]; Knudsen et al. 2014; Wörmer et al. 2014; Wurtzel et al. 2013; Hood and Soukharev 2011; Roy and Haigh 2010; Seppälä et al. 2009). A similar pattern of correlation was found for Caspian Sea level variability (Kaftan et al. 2018).

Cycles of ocean temperature have been linked with known cycles of solar modulation in the Pacific (Douglass and Knox 2015 [1]) and global (Douglass and Knox 2015 [2]) datasets, and with solar activity modulation of circulation-coupling in the subtropical ocean gyre in the Pacific (Liang and Wu 2013).

Almost all of the previously proposed correlations were confirmed by either Zherebtsov et al. (2019) or Xiao et al. (2017).

Stepping back and looking more broadly at global land and ocean temperatures, recent work has become increasingly focused on the large-scale mechanisms of the forcing**. The strength of Earth’s magnetosphere in conjunction with solar modulation of GCR** appears to strongly affect the long-term temperatures of both land and ocean (Audu and Okeke 2019; Kitaba et al. 2017).

4) Precipitation

The precipitation influence of space weather is driven by both wave and particle energy. The oscillations, patterns and temperature forcings we have already described in this chapter are certainly strong modulators of precipitation patterns.

It is also critical to understand that galactic cosmic rays (GCR), coronal mass ejections (CMEs) and solar energetic particles (SEP) affect the cloud cover and atmospheric electricity (Chapter 5) on short timescales. They contribute, in paramount fashion, to the results of the following relevant studies, as much or more than the modulation of large-scale oscillations and temperatures.

a. United States

i) There is a significant relationship between sunspot number and monthly average precipitation in the USA, with significantly improved forecast model performance when sunspots are included (Nitka and Burnecki 2019).

ii) In the southwest United States, high solar activity appears to force lower precipitation, and low solar activity brings more precipitation (Asmerom et al. 2007), but the reverse is true of the northwest states (Lui et al. 2014). The idea of a solar cycle influence over drought areas in the western United States is not a new one (Cook et al. 1997).

iii) Solar minima appear to force droughts in the central-eastern United States, sometimes with a few years lag. (Springer et al. 2008).

b. South America/Caribbean

i) Rainfall in Brazil shows short-term correlations with space weather events, and with sunspot cycles and their harmonics (Le Mouel et al. 2019; Almeida et al. 2004; Gusev et al. 2004).

ii) Centennial-scale solar forcing patterns across much of the South American monsoonal zones have been discovered (Antico and Torres 2020; Novello et al. 2016).

iii) In southern Argentina, regional rainfall was found to be positively correlated with both sunspot number and geomagnetic activity (Heredia and Elias 2013), but that result failed to remain statistically significant in a subsequent analysis (Heredia and Elias 2016) until geographical coverage was restricted to effects on the monsoon-dependent regions, which actually strengthened the original results (Novello et al. 2016).

iv) Extended droughts appear in Jamaican records during the Little Ice Age, which was also during the last solar grand minimum; a southward push of Hadley cells is likely responsible (Burn and Palmer 2013).

c. Europe

i) The western Mediterranean hydroclimatological variability shows centennial correlations with the solar cycle on the 200-year scale (Ait Brahim et al. 2018). Most European rainfall variability on shorter scales is due to processes we have already examined, such as the phase status of the NAO and the positions of the jets and polar vortex.

ii) The region of the Alps is prone to greater and more numerous flood events during solar minimum due to the influence on Hadley cells and a more southerly position of the North Atlantic circulation (Wirth et al. 2013).

iii) The greater Tuscany region of Italy has shown higher flood potential at both sunspot maximum and minimum (extremes), indicating an influence of both solar activity and GCR compared to the ascending and declining phases of the cycle (Casati et al. 2017).

iv) The studies that have discussed harsh European winters (previous subsection) during solar minima included the increased snowfall that plagues the region during such solar minima, often driven by the NAO, and which can lead to melt-driven flooding across the Alps. The studies on solar forcing of NAO indicate that high solar activity leads to warmer/drier conditions over most of the continent but with a cooler/wetter southern maritime region that extends into northern Africa.

v) On the other side of the scale, high GCR (low solar activity) leads to cooler/wetter climates across the majority of the continent with a 3 to 4-year lag (Laurenz et al 2019).

vi) Both temperatures and precipitation in Serbia show evidence of modulation by the solar wind streams from coronal holes (Todorović and Vujović 2014).

d. Asia

i) Sediment analysis in northern China indicates that decadal, centennial and millennial monsoon oscillations are linked with solar activity (Wang et al. 2020; Chen et al. 2019[2]; Huang et al. 2019; Ma et al. 2019; Zhu et al. 2019 [2]; Chu et al. 2014).

ii) In greater eastern Asia, we see solar maximum push the monsoon flow northward and create more variability from year to year than occurs during solar minimum (Zhao et al. 2017; Zhao and Wang 2014).

iii) Geomagnetic maximum (the declining phase of the sunspot cycle) appears to correlate well with extreme flooding and course-shift events of the Yellow River (Wang and Su 2013).

iv) Sunspots have shown a relationship with rainfall variability in Bangladesh, presenting the most-influential factor over precipitation systems in the model used (Rahman et al 2019).

v) Using both global data sets and ground-based observations in India, a relationship between the sun and the tropical easterly jet was found, whereby solar maximum increased

its wind speeds, solar minimum decreased its wind speed, and a relationship to the Indian monsoon rainfall occurs on a delay of approximately 13 years (Ratnam et al. 2014).

vi) Xu et al. (2015) found a correlation between grand solar minima and the millennial abrupt monsoon failures in India.

vii) 11-year cycles show up in various monsoon data in East Asia (Xiao et al. 2017).

The Asian monsoon is affected by ENSO, ocean temperatures, the Walker circulation, Hadley Cells, and clouds (Chapter 5); based on what we already know, solar forcing of the monsoon is inevitable.

Others have found similar correlations in India (Hiremath et al. 2015), but the influence of solar activity/GCR is in dispute. Van Loon and Meehl (2012) found a positive enhancement of the Asian monsoon with sunspot peaks, but more-so near the coastlines than farther inland. Low solar activity (higher GCR) may locally enhance the monsoon, while high solar activity (lower GCR) may decrease precipitation across the region overall (Badruddin and Aslam 2015).

Maitra et al. (2014) may have previously resolved that issue in finding both positive and negative correlations, separated by regional geography, and which have oscillatory behavior over time. Chaudhuri et al. (2015) found a chance for lower rainfall during higher GCR flux. The issue was further resolved as being the result of the differing regional/local modulation of the NAO and planetary wave train on different regions of Asia, as they are strengthened and modulated over time by the solar cycle (Chen et al. 2019[1]).

More Notes:

- Variations in Australia’s and Indonesia’s monsoon seasonal variability appear to be driven by solar activity (Heredia and Elias 2016). This confirmed previous findings that grand solar minima drive more extreme rainfall across the entire region (Steinke et al. 2014).

- Nigerian precipitation records comport well with the 11-, 22-, and 44-year solar cycle, exactly like the patterns seen in the temperature records, but they do so with more-varying amplitudes than is seen with temperatures (Okeke and Audu 2017).

- Antarctic region precipitation appears to be driven by solar activity, GCR, and large oscillations like the ENSO and PDO, which are also modulated by solar activity (Mayewski et al. 2017).

- Jet stream blocking during sunspot minima increases snowfall over Greenland (Adolphi et al. 2014).

There are no general rules for the globe when it comes to a specific space weather event or solar cycle trend; some areas will be hotter, others cooler, while some areas see more rainfall, and others less. These differences are largely related to the amplified effects of solar activity on the NAO,

ENSO, PDO and the semi-permanent lows like the Aleutian low, Icelandic low, Amundsen low, Azores high and Siberian highs.

While there is still considerable effort to restrict the sun to that 0.1% variability (Gueymard 2018), with no regard for even the solar forcing studies published in the very same journal, the room for irradiance to explain the variety of forcings is dwindling. Meanwhile, other scientists are literally making pleas to the world of geophysics to recognize alternative forcing pathways from space weather phenomena like cosmic rays, and the entire atmospheric vertical column reactivity to changes in the solar wind (Le Mouel et al. 2019; Maghrabi 2019; Francia et al. 2018).

Key Points:

1) Solar activity has somewhat varying influence on hot/cold and wet/dry across different regions of the globe. These variations are based on the varying effects of large scale modes like ENSO and NAO.

2) Solar minimum/maximum drives colder/warmer temperatures during winter/all year for much of the northern hemisphere.

3) Grand solar minimum can disrupt the normal monsoonal patterns, leading to catastrophic droughts and floods last seen during the "little ice age."

4) The temperature- and precipitation-focused studies demonstrate the correlations expected to be seen based on solar forcing of large scale oscillations.

   For example, solar minimum drives negative phase NAO and Weak Polar Vortex >
   Both those events are expected to produce colder and harsher winters in the UK >
   The temperature studies confirm the expected colder patterns in solar minimum.

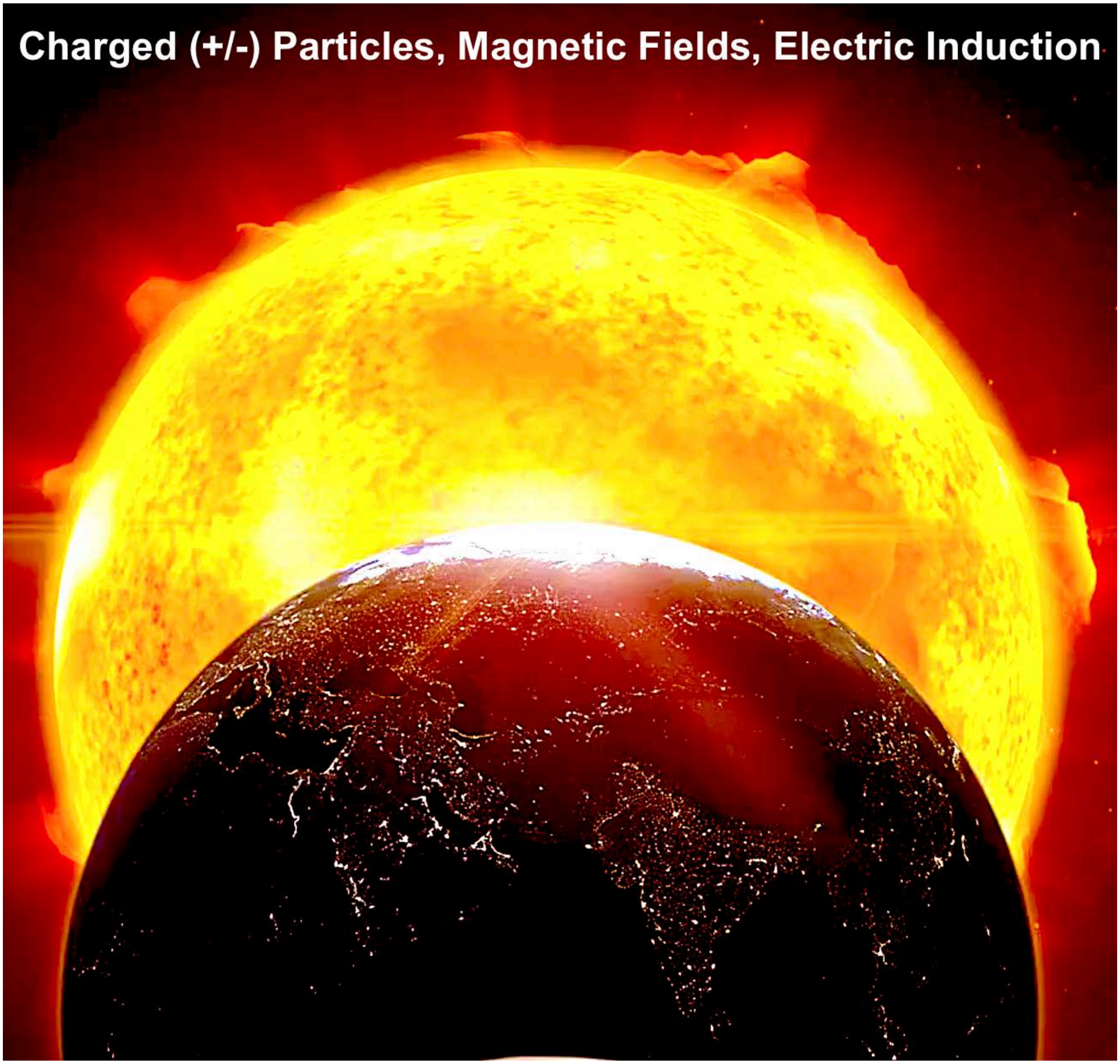
Not a single one of the particle forcing studies described so far was allowed to be part of the climate change discussion before CMIP6 (starting 2022). This is why we hear what we hear in the news- these studies simply "do not count" yet.

The same goes for what comes next...

5.0 It's Electric

Focus in the field of solar forcing has somewhat shifted away from long-term oscillation/mode and temperature-based studies, and more towards short-term effects, circulation modulation, and **the role of electromagnetic coupling between the atmosphere, ionosphere and magnetosphere.**

In electromagnetic coupling models, there is a direct electrical effect on the pressure, temperature, wind speed, and cloudiness of the troposphere (Bucha 2019; Freeman and Lam 2019; Maliniemi et al. 2018). This is truly the only way we would see total-vertical-column changes in the atmosphere during solar wind changes (Frederick et al. 2019; Francia et al. 2018; Harrison et al. 2013).


Charged (+/-) Particles, Magnetic Fields, Electric Induction

5.1 Brief Introduction to Electromagnetic Coupling

It has been known for more than 30 years that solar UV influences the lower stratosphere (Donnelly and Heath 1985), and the reality of its **thermal coupling** effects on the troposphere below came in the years that followed. This is the slow 0.1% variability of TSI in the old models.

Chapter 4 was filled with numerous studies that have now strengthened the case for broader scales of that thermal coupling (like ENSO or NAO), and also for **electromagnetic particle coupling** resulting when space weather affects the magnetosphere, ionosphere and upper atmosphere. Foundational works describe this coupling from the perspective of correlating temporal-changes in space weather and atmospheric parameters, which has been tied to patterns in the atmospheric electric potential gradient (Silva and Lopes 2017; Harrison et al. 2013; Solanki et al. 2013; Troshichev 2008… everything in the references from Tinsey or Lam).

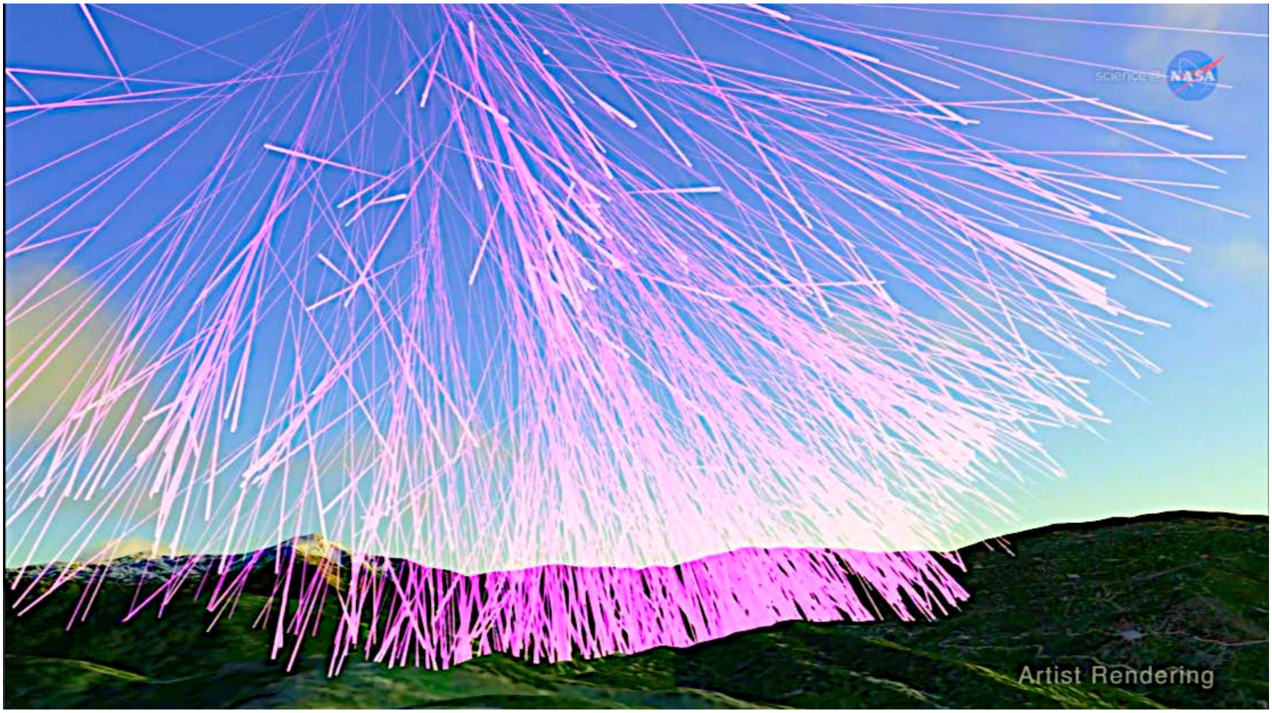
While we have learned that solar wind, high energy protons and cosmic ray atomic nuclei are playing a role, we have not yet described *how* the solar forces act on the weather and climate.

On one hand, annual/seasonal temperature and precipitation fluctuations are likely the result of the broader thermal coupling and modulation of major oscillations. On the other hand, the short-term correlations between the sun and weather, across the atmosphere, can only be explained by short-term electromagnetic changes.

Key Points:

1) Old: Thermal coupling downward from stratospheric heating by irradiance
   New: Go beyond TSI and look at other Earth-layers, include particle energy, and expand thermal coupling to oscillation/circulation/cell modulation
   Future: Electromagnetic coupling of the total vertical atmospheric column

2) Electric coupling mechanisms exist from the upper electric layers to the ground, connecting the entire vertical atmospheric column.



5.2 GCR, SEP, Earth Electrons and Clouds

This section focuses on what *was* a heated scientific debate about whether galactic cosmic rays (GCR), solar energetic particles (SEP), and electrons from the magnetosphere/ionosphere can increase cloud cover.

Earth electrons from the magnetosphere, ionosphere and Van Allen belts can reach extreme energy levels and can penetrate into Earth's atmosphere during CME compression of Earth's fields- such as those from the equatorial ion fountain (Section 1.8).

Rather than the wave energy of irradiance or the particle interaction/induction with Earth's magnetic fields, cloud studies focus on the particles that penetrate into the atmosphere. These are mostly cosmic rays, but the rare SEP events and high-energy Earth-electrons can contribute to this population as well.

The story of this sub-field is one of the most incredible in solar climate forcing.

1) The Cosmic Ray Conflict

Henrik Svensmark contributed a theory that galactic cosmic rays (GCR) and other energetic cosmic particles were related to cloud processes, implicating a solar modulation of clouds, and therefore, numerous related climatological parameters. He is widely considered to be the father of this field of study.

a. Initially, it was unclear whether the GCR modulation of the lower-altitude clouds is significant (Voiculescu et al. 2013; Patterson et al. 2013; Harrison et al. 2013; Troshichev 2008; Tinsley et al. 2007; Vieira and da Silva 2006; Tanaka 2005; Shea and Smart 2004)...

...or not (Rawal et al. 2013; Krissansen-Totten and Davies 2013; Calogovic et al. 2010).

b. Some studies found a small correlation at low altitudes (Brown 2008), other studies found a 20 - 30% correlation in low/mid-altitude clouds (Erlykin et al. 2010 [1]) and uneven or anti-phase forcing of high vs low clouds (Erlykin et al. 2010 [2]), but not so much in the total cloud cover (Erlykin and Wolfendale 2011).

c. Krissansen-Totten and Davies (2013) failed to find any correlation using the MISR data from the Terra Satellite. Similarly, Calogovic et al. (2010) failed to find a cloud signature related to GCR in the ISCCP D1 cloud-cover data.

d. Sun and Bradley (2002) found no correlation whatsoever when analyzing 1983 - 1993 using ICSSP data, but Laken et al. (2009) found an immediate decrease in global liquid water cloud fraction upon Forbush Decrease.

e. Kancírová and Kudela (2014) found a correlation over long solar cycles, but when averaging over one-year timescales, they found no correlation. Note: We see very few one-year correlations of solar forcing; they are either rapid (minutes-days) or have at least a few years lag.

f. Several significant, but weak, correlations were discovered in mid to high-altitude cloud cover by Rohs et al. 2010.

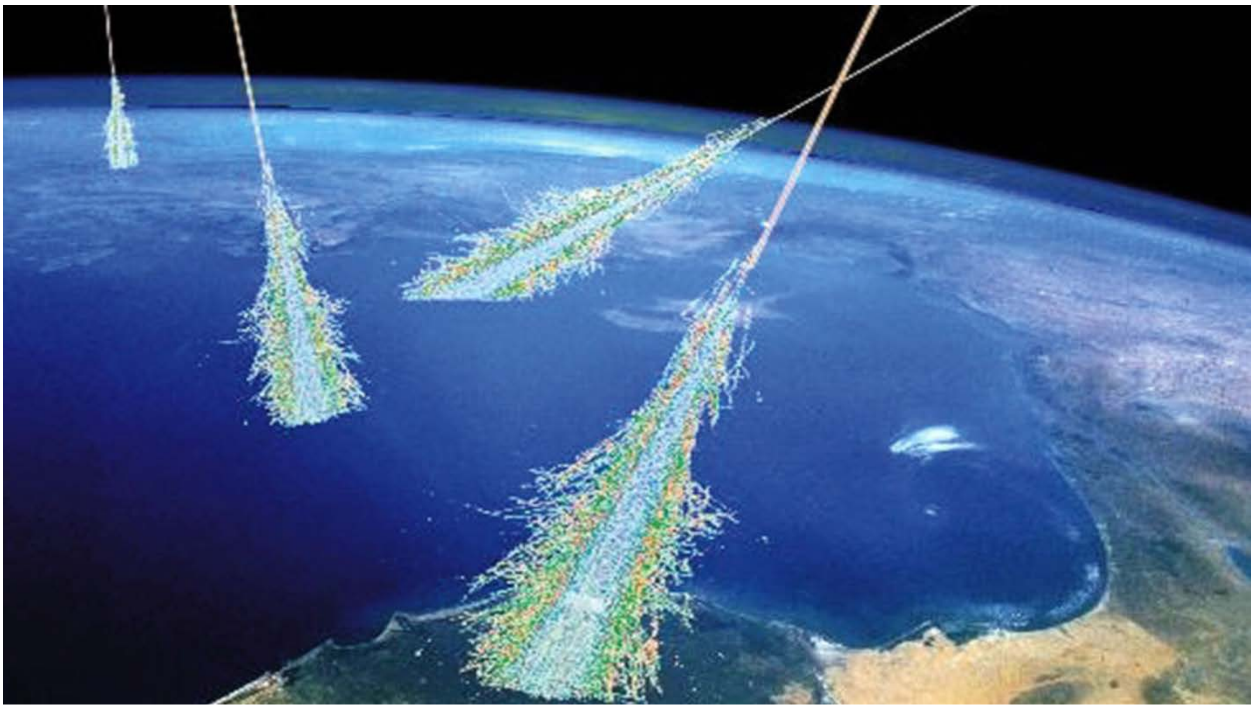
g. <u>As of 2014, it was clear that there was a need for clarification in this field.</u>

As we learned with CME delivery of a 2nd “punch” of solar energetic particles (SEP), and with the added Earth-electrons from the CME-compressed magnetosphere and ionosphere, there is actually an increase in cloud-forcing potential coinciding with the drop in GCR **for a small region of the sun-facing side only**.

The early focus on only GCR-reduction during CME impact does not comport with the real space weather situation of penetrating particles due to that impact.

2) Winds of Change and Resolution

a. Recently, in accounting for that exact confusion between GCR decrease and SEP/electron increase, the scales have tipped. Since 2014 there has been a definitive shift in favor of cloud modulation by space weather (Christodoulakis et al. 2019; Lee et al. 2019; Zhang et al. 2019; Lam et al. 2018; Zhang et al. 2018; Fernandes de Moraes et al. 2017; Kumar et al. 2017; Lavigne et al. 2017; Regi et al. 2017; Artamonov et al. 2016; Didebulidze and Todua 2016; Lam and Tinsley 2016; Veretenenko and Ogurtsov 2016; Lam and Tinsley 2015; Avakyan et al. 2014; Maitra et al. 2014; Yu and Luo 2014).



b. With this overwhelming trend, the mechanisms of cloud modulation are being revealed as well:

i) The energetic particles introduced and forced through the atmosphere appear to be excellent controlling drivers of aerosol-focused condensation and ice nucleation in clouds (Yu and Luo 2014). In some circumstances, this aerosol electron scavenging may be dominant over more well-known nucleation processes (Zhang et al. 2019).

ii) Increases in penetrating particles result in ionization of ambient air, changes in the microphysical electrodynamics of the cloud region, invigoration of thunderstorms, increase in atmospheric turbulence and consequently, an increased cloud profile and risk of major hail events (Lee et al. 2019; Zhang et al. 2019; Fernandes de Moraes et al. 2017; Lavigne et al. 2017; Artamonov et al. 2016; Zhou et al. 2014; Tinsley et al. 2007; Tinsley 2000).

iii) The mechanism was similarly described as redistribution of condensation nuclei in the lower-troposphere by the vertical electric components of the global atmospheric electricity (Zherebtsov et al. 2005).

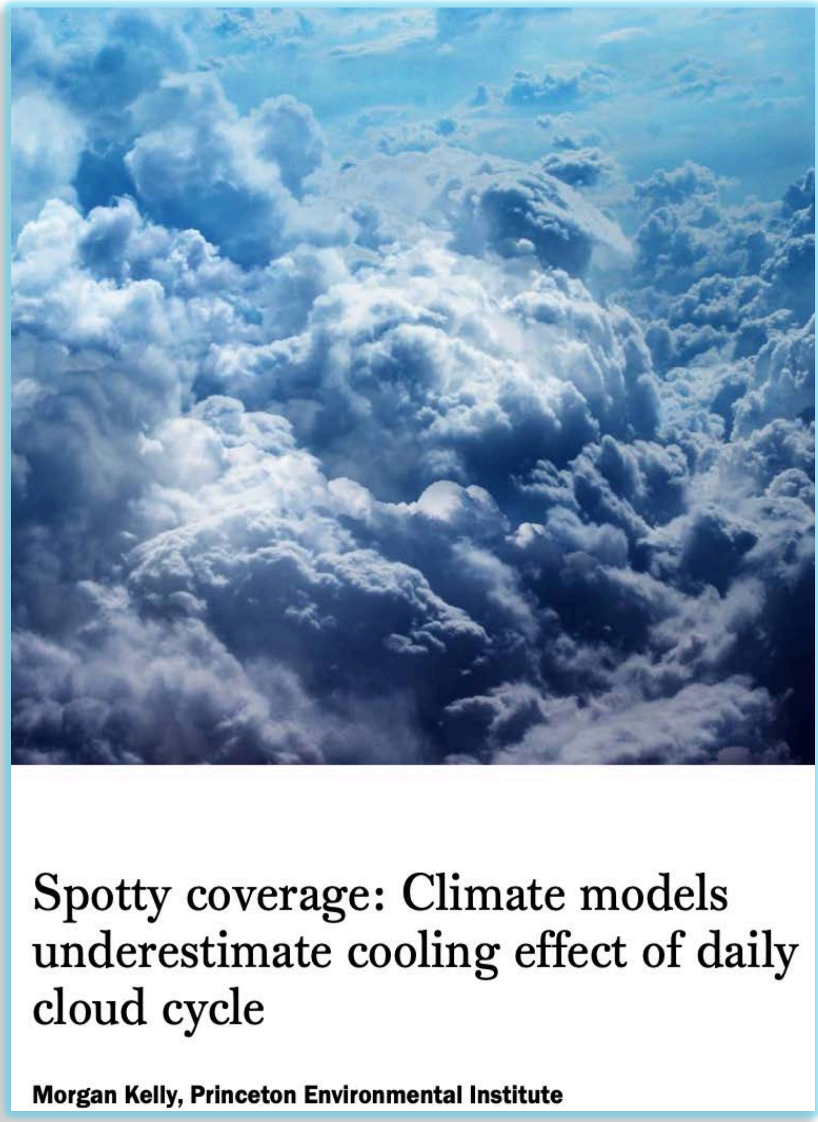
iv) In addition to ionizing the aerosols, water particles and other molecules in the air, the penetrating cosmic rays (and their cascade particles) are directly deposited into the atmosphere onto dust, water, or as their own potential condensation nuclei material.

The conclusions of these studies are essentially the same: over both short and long timescales, space weather modulates 1) the ionization conditions of ambient atmosphere, 2) the direct deposition of condensation nuclei, and 3) the vertical current density that affects storms and cloud cover.

In the short term, SEP and earth electrons precipitating during geomagnetic disruptions enhance the global atmospheric electricity and nucleation processes, and over longer time periods, the solar modulation (anticorrelation) of GCRs determines the ambient conditions (ionization, distribution of condensation nuclei) outside geoeffective space weather events.

The mechanisms of cloud forcing implied by the available literature indicate that lightning rates should increase alongside the introduction of GCRs, SEP, and earth electrons; there is more lightning in general during solar minimum, but with strong, short-term lightning increases during space weather impacts at Earth in solar maximum. In the next section we will examine the merit of such a logical extension of these cloud-based ionization mechanisms to lightning.

Recently, cosmic rays have begun to complete the thermal coupling puzzle of solar forcing, while illuminating much about the electromagnetic coupling. The SEP and earth-electron forcing gave the extra energy element needed in the models, and the cosmic rays provide the cloud-driven albedo cooling of sunspot minimum (Audu and Okeke 2019; Chepfer et al. 2019).


Spotty coverage: Climate models underestimate cooling effect of daily cloud cycle

Morgan Kelly, Princeton Environmental Institute

Image of online article from Princeton.edu covering the work of *Yin and Porporato* 2017*

Clouds have been shown to be primary climate controllers, even in studies not-at-all investigating a solar/cosmic ray forcing (Strommen et al. 2019, Yin and Porporato 2019; Yin and Porporato 2017).*

*Yin and Porporato (Princeton) tried to turn these facts on global warming, and link it to a solar-like decadal cycle (Yin and Porporato 2018)… and they were not well received, being forced into self-publishing on Cornell's pre-print arXiv.org. They left those parts out of their 2019 work cited above, and were once again received into a top journal.

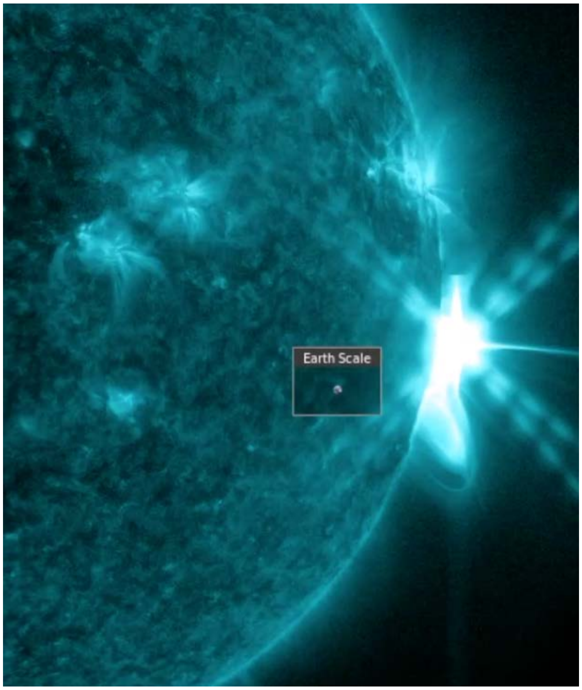
Key Points:

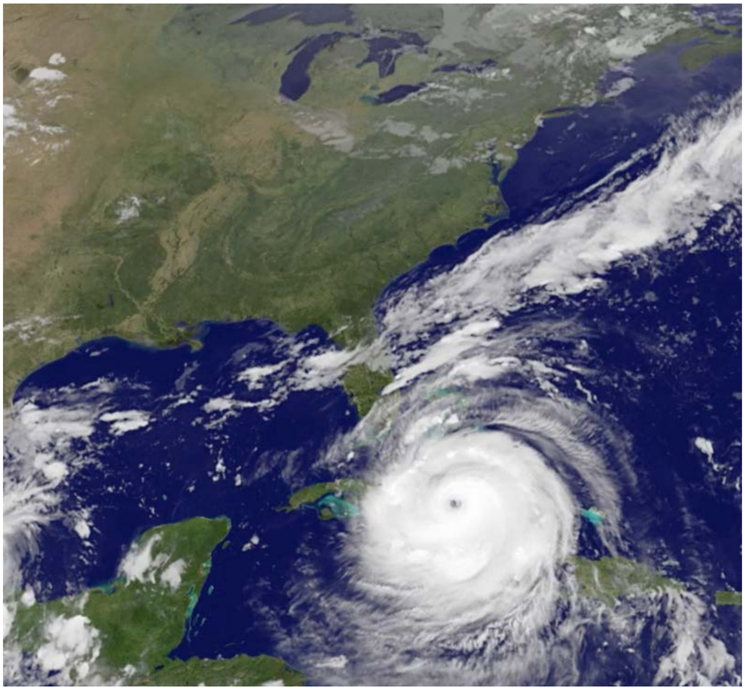
1) Years of conflicting studies have shifted toward a confirmation that GCR/SEP/electrons can modify the clouds; this is mostly due to GCR.

2) Hypothesized mechanisms include direct aerosol production from cosmic ray nuclei, and the cosmic ray ionization of the atmosphere, resulting in attraction of vapor/dust.

3) The GCR mechanisms that affect cloud cover are also the known pathways to affect hail formation (condensation nuclei).

4) Clouds are taking on a larger role in climate models as scientists better understand their cooling vs heat-trapping properties. This greater role is also a role for space weather.





SDO and NOAA Satellite image of the major solar flare of September 2017 and Hurricane Irma.

5.3 Space Weather-Driven Lightning, Storms & Cyclones

The study of lightning induced by space weather is in its infancy, but researchers already have made numerous findings indicating that a similar relationship exists to that of space weather and clouds. The most easily tracked correlation in this area of focus is over the 11-year solar cycle, in which the solar maximum decreases galactic cosmic rays (GCR) and lightning rates via a stronger heliospheric magnetic field, while the solar minimum offers an increase of GCRs and lightning.

1) Lightning Forcing

a. The direct particle penetration energy introduced to the Earth system, and corresponding modulation of lightning and atmospheric electricity, was noted numerous times earlier this century (Owens et al. 2014; Neto et al. 2013, Harrison and Usoskin 2010); lightning is directly correlated with GCR and anticorrelated with long-term sunspot number.

b. Solar energetic particles (SEP) and Earth electrons (forced downward by impacting space weather) were hypothesized to modulate lightning activity over short timescales via their rapid effect on the atmospheric particle flow- the AC and DC global electric circuit systems. This would add to the cosmic ray reduction (Forbush decrease) during CME impact. The GCR effect was said to be more prevalent over sunspot cycle timelines (Nicoll and Harrison 2014; Williams et al. 2014; Harrison and Usoskin 2010).

c. High-speed solar wind streams drive increases in lightning rates across Europe. These can reach 33% increases above average, persist for ~40 days, are mirrored by MET-observed ‘thunder days’, and appear directly correlated with CME-driven increases in SEP and Earth electrons (Scott et al. 2014).

d. When isolating the Phi angle variations in the solar wind (Earth crossing the heliospheric current sheet - Section 1.1), short-term lightning increases over Europe can reach 40 - 60% (Owens et al. 2014).

e. Owens et al. (2015) determined that the changes to Earth’s magnetospheric and ionospheric structure were driving the change in lightning rates, but also speculated it was merely a redistribution of lightning rather than a change in global strike rates. In this hypothesis, the action on large-scale pressure cells and oscillations would cause the redistribution, without direct production of lightning.

f. Many studies *do* find such an increase in strike rates, including ones involving variation in Schumann resonance modulation by space weather, like Williams et al. (2014). The conflicting studies have been rectified in the last few years much in the same way that the cosmic ray confusion has been resolved.

h. In the last few years, most of the hypothesized forcing pathways and associated correlations have been confirmed, strongly supported, or directly tied to solar cycles/events via literature reviews and location-based lightning/GCR tracking. It is not one or the other, it is all of them working in different ways. The existence of these forcings has been repeatedly demonstrated for GCR, SEP, and magnetospheric electrons (Zhang et al. 2020; Okike 2019; Okike and Umahi 2019; Jeon et al. 2018; Kumar et al. 2018, Miyahara et al. 2018; Chronis and Koshak 2017; Makhmutov et al. 2017; Silva and Lopes 2017). These most-recent papers have confirmed, but pulled back on, the importance of SEP and electrons - noting that the GCR are dominant, and that

GCR cascades include protons and electrons, and that it may be difficult to ascertain whether they are from the sun or GCR.

i. With the correlation and pathways fairly well defined we can look to other studies that focus on specific locations of interest, and which have found the same correlations:

i) In the United States, the heat-driven lightning in the summer drowns out any correlation with space weather; however, winter months show a strong correlation with the modulation of GCRs and might *directly* account for 1.6 % of lightning strikes overall via conductivity modulation and influence on electrification pathways, which would further influence later strikes (*indirectly)* (Hare et al. 2017; Chronis 2009).

ii) Short-term forcing of lightning decrease during Forbush decreases (drop in cosmic rays during CME impact) has been confirmed in the United States, Africa, and on a global scale (Okike 2019; Okike and Umahi 2019).

iii) In Brazil, most of the country shows a significant anticorrelation over the sunspot cycle in lightning strike number, mirroring the hypothesis of GCR-driven modulation (Neto et al. 2013). This correlation extends throughout the tropical region (Zhang et al. 2020).

iv) Trivandrum, India, demonstrates the same anticorrelation with lightning in both sunspot activity and geomagnetic records (Girish and Eapen 2008). India and the surrounding countries have more lightning deaths than any region in the world.

v) Miyahara et al. (2018) confirmed two previous findings of space weather forcing of lightning in Japan. They found that when the particles penetrate into the atmosphere they either create condensation nuclei (which reduce atmospheric resistivity and create a better pathway for electric current) or directly ionize existing air molecules.

vi) Lightning forcing was highlighted as a potential major future avenue for discovery in the space weather field in Knipp (2019).

vii) There is a separate and growing body of evidence for a connection between lightning counts and ice-mass precipitation in atmospheric science literature (Farnell et al. 2017; Wapler 2017; Deierling et al 2008; Latham et al. 2007) which further increases the chances that hail is connected to GCR and is subject to space weather modulation in the same way as clouds and lightning.

The energy that affects large-scale circulations/oscillations is the same energy that drives cloud cover and lightning; as one might logically conclude, this energy is available to the most powerful storms on Earth as well.

Photo: NASA.gov/ISS

2) Storm Forcing Introduction

a. Hurricanes Katrina, Rita, and Wilma (all in 2005) demonstrated a connection with space weather modulation of the atmosphere (Todorović and Vujović 2014).

b. Todorović and Vujović (2014) built on a volume of previous works correlating solar activity with tropical storm activity near Mexico, the Caribbean/Gulf of Mexico, Taiwan and China Seas (Hung 2013; Hutton et al. 2013; Hodges and Elsner 2012; Hodges and Elsner 2011; Elsner et al. 2010; Elsner and Jagger 2008; Perez-Peraza et al. 2008). This essentially sparked the birth of a new field of short-term extreme solar forcing of weather.

c. The correlation between space weather events and tropical storm activity has been repeatedly confirmed. (Kim et al. 2017; Shu Gao et al. 2017; Haig and Nott 2016; Rojo-Garibaldi et al. 2016; Trouet et al. 2016; Zhou et al. 2016 [2]; Bony et al. 2015; Hodges et al. 2014).

d. A direct relationship between geomagnetism and global tropical cyclones was found to be tied to variations in solar wind and other particle forcings, including the 2017 uptick of Hurricanes Irma and Maria (Nina et al. 2019; Prikryl et al. 2019; Vyklyuk et al. 2019; Li et al. 2018; Vyklyuk et al. 2018).

i) In addition to finding significant correlations between geomagnetic indices and tropical cyclogenesis, a key relationship was discovered in absolute vorticity, relative humidity and vertical shear, implicating a non-irradiance-based forcing of tropical cyclones (Pazos et al. 2015).

ii) There is evidence that small changes in upper-troposphere heating by the sun can affect extratropical storm tracks and perhaps the position of the tropical rain belts (Bony et al. 2015; Butler et al. 2010).

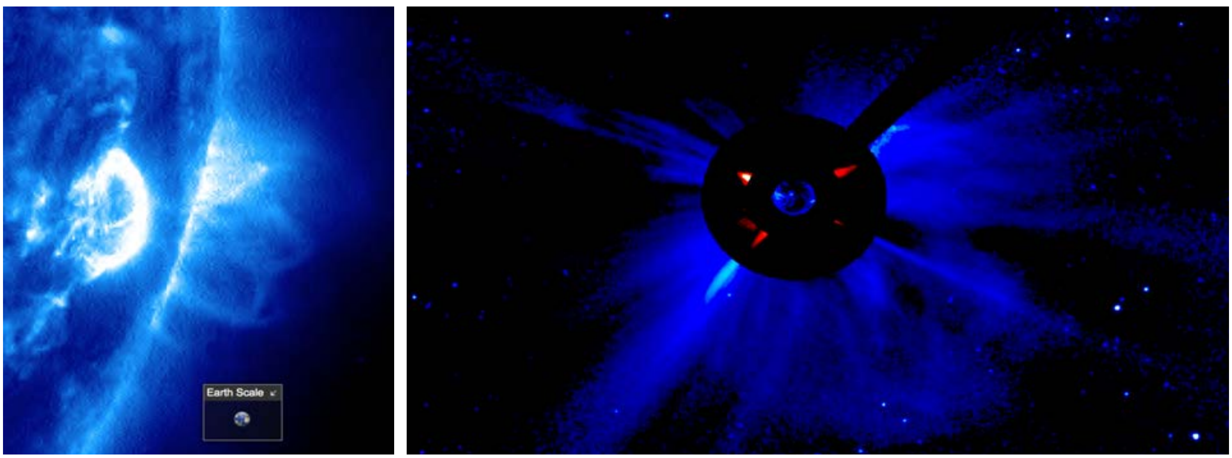
iii) The extension of these processes to the extratropical regions seems bolstered by recent evidence that disturbed geomagnetic conditions favor extratropical cyclone intensification (Karakhanyan and Molodyk, 2017; Prikryl et al. 2017; Artamonov et al. 2016; Prikryl et al. 2016). This author submits that Hurricane Kate (2015) is a prime example of this extratropical reach of the sun, as well as Tropical Storm Chris (2018).

iv) Faris Wald of Santa Fe, NM, USA, won the 2017 National Middle School Science Championship (The Broadcom MASTERS), for demonstrating a connection between coronal holes and tropical cyclones. He went on to make the Top 100 the next year in the Google World Championship. He continues his studies today (2020) as he matriculates through high school.

Faris Wald at the Broadcom MASTERS Competition

3) Hurricane Katrina

Let's come back to Hurricane Katrina: looking into space weather archives, a plunge into sunspot cycle minimum in early 2005 was violently interrupted in August with solar flares, CMEs, SEP events and geomagnetic activity during the formation and intensification of the terrible Hurricane.



These images are from the SOHO satellite on August 22nd, 2005, the day before the formation of Katrina. During what should have been a time of quiet solar activity, a strong arc solar flare, seen on the left, released a powerful CME. On the right, the SOHO satellite coronagraph for the event has been darkened so that the only visible features outside of the C2 radius (red) are the white dots of background stars, the straight bars of light and dark (which are coronal jet streamers and the satellite arm holding the central disk, respectively), **and a blue fuzzy/hazy patch ~50x bigger than the sun**, centered off to the right side and the south.

The fuzzy blue patch on the right is the CME that came from the solar flare. It was an unexpected and dramatic shift in electromagnetic energy to Earth. The bright portions near the 2 and 7 o'clock positions show the edges of a 180^{o} CME- it impacted half the solar system.

The sun and tropical storm activity returned to quiet for only about three weeks when an equally powerful uptick on the sun in September was matched by a rare 5-cyclone event in the Pacific Ocean - this did not happen again until a 6-cyclone event occurred in June 2015.

4) Storm Forcing in Summer & Fall of 2015

a. In late June 2015, a rare Kp8 geomagnetic storm resulted from multiple CMEs and a coronal hole stream impacting in succession. Within two weeks, there were six cyclones in the Pacific Ocean at the same time. This has only happened twice before, one of which was in October 1979 during the monthly sunspot peak of that year. Then, the sun went quiet for two months.

b. A flurry of solar flares August 26 - 29, 2015 ionized the Earth’s atmosphere and led to three Category-4 hurricanes in the Pacific Ocean (Kilo, Ignacio, Jimena – image above) at the same time on August 30. It was the first occurrence of three simultaneous Category-4 storms in the Pacific on record. The sun was quieter for most of September.

c. A large solar flare in early October 2015 disrupted the entire inner solar system with a strong SEP event and was immediately followed by Hurricane Joaquin, which caused a 1000-year-flood in South Carolina (without even making landfall), and a rare hurricane-force storm in the Mediterranean Sea.

d. A strong geomagnetic storm in late October 2015 occurred as a weak Hurricane Patricia was forming. Patricia intensified during the geomagnetic storm to sustain 215 MPH winds - a world record.

e. One week later, without causing geomagnetic storms, two M-class solar flares erupted on October 31 and November 4, 2015. Each flare occurred at ~noon in the western Indian Ocean. Each flare was followed immediately by a rare-location cyclone formation in the northwest Indian Ocean, and both struck Yemen in the first week of November 2015. This Yemen event would be repeated three years later:

> During the low point of sunspot cycle minimum in May 2018, numerous solar flares erupted unexpectedly (no geomagnetic storms). Again, twin cyclones struck the Yemen/Oman and East Africa Region in the following days. That is two flaring events, three years apart - no geomagnetic effects, wave energy only. Two cyclones hit the NW Indian Ocean each time.
>
> During the 2015 events in Yemen there was also a rare-location extratropical storm Kate off the US coastline. During the 2018 events, Tropical Storm Alberto hit the Gulf coast, and yet it managed to create a 1000-year flood in Maryland. During the same type of “flare-but-no-geomagnetic-storm” space weather in both 2015 and 2018, we saw the same geographical forcing of intense storm systems on opposite sides of the globe. We will come back to 2018 later.

5) Storm Forcing in 2016

a. After the Yemen 2015 cyclones, calm ensued until early January 2016, when the sun released multiple CMEs and solar flares just as a coronal hole stream was already causing geomagnetic storms on Earth. Tropical storm Pali became the earliest central Pacific cyclone on record just days later on January 11th, and Alex formed into a rare winter hurricane in the Atlantic later that week.

b. February 18, 2016 was the next solar uptick. A fantastic magnetic explosion on the sun was caused by a plasma filament eruption while a coronal hole was causing geomagnetic storms at Earth. Cyclone Winston became the strongest cyclone to make landfall in the history of the South Pacific Basin just 24 hours later. The heliographic latitude of the filament eruption was the same geographic latitude of Cyclone Winston.

c. The sun was very quiet until April 18, 2016 when an M6 solar flare erupted amidst weeks of near-complete silence in terms of solar flaring. Within 24 hours, Cyclone Fantala intensified to become the strongest Indian Ocean storm in history.

d. The next major weather record wasn’t set until June 2016, when Colin became the earliest ‘C’ named storm in the history of the Atlantic Basin. This occurred during a geomagnetic

storm that included significant penetrations of solar plasma into Earth's atmosphere. Another silent spell on the sun ensued.

e. In late September 2016, a powerful coronal hole ended three months of silent space weather. During the peak of the geomagnetic storm, Typhoon Megi intensified rapidly into a category-4 storm, and to the south on the same longitude, an extra-tropical cyclone intensified and took out power to the entirety of South Australia. Coronal hole stream impact occurred when that longitude was in the noon position, meaning that it took the force of the magnetospheric/ionospheric compression and vertical current enhancement.

f. The same coronal hole triggered Kp7 geomagnetic storm conditions on its next pass by Earth in late October 2016; it matched the most powerful solar storm of the year. During the peak of the storm, Hurricane Seymour intensified to become the strongest East Pacific storm of the entire season.

Decades worth of storm records fell in the span of 18 months; every one of them matched up with a solar storm during a period in which inactivity on the sun was vastly more prevalent than activity over the long-term. This is a key factor in identifying the solar-hurricane connection.

The sun was active almost constantly from 2012-2014, but after was few and far between after the sunspot maximum. When the sun is most active it is difficult to differentiate these forcings, and overall the peak of sunspot maximum tends to disrupt the convective storm engine with *too much* stratospheric heating. During sunspot minimum there is a long-term peak in cosmic rays, creating the same trouble of differentiation between normal/random events and those influenced by space weather- unless surprise space weather occurs to break the silence.

Diligent observations over years have indicated that the ascending and declining phases of the sunspot cycle, when solar activity interrupts periods of relative quiet, provide the best times to characterize this relationship. The ascending phase of the next sunspot cycle is beginning in 2020 and is expected to take 2-3 years to rise to peak. After 2-3 years of peak solar activity, the declining phase will last 2-3 more years.

6) The Tremendous Events of September 2017 and Beyond

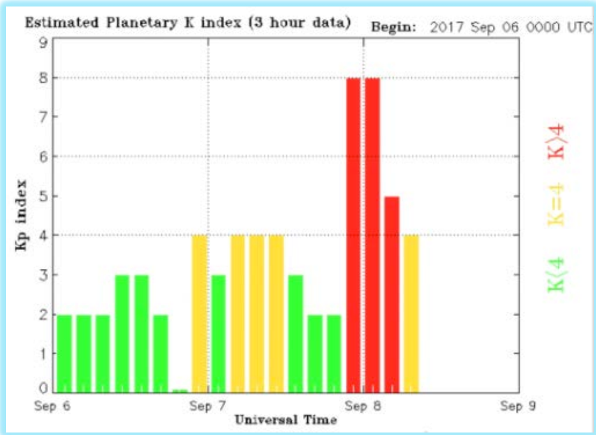
The September 2017 event is a perfect example of how things can get bad very quickly, and it has gone down in the space weather history books. Unfortunately, it has gone down in the hurricane history books as well. The year 2017 was about as quiet on Earth and sun as you can get, until September:

a. The largest solar flare and SEP event in 12 years, a days-long flurry of unexpected sunspots/solar flares, and a days-long geomagnetic storm that peaked at Kp8 occurred September 3-13, 2017.

b. The uptick in sunspots actually began in mid-August 2017, just as Hurricane Harvey formed and began strengthening on approach to Texas.

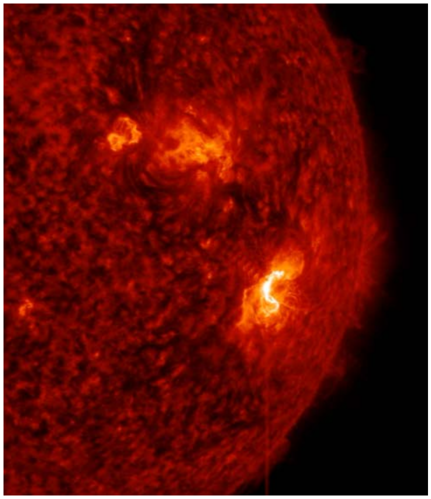
c. The initial X class flares happened in the first week of September along with the most powerful geomagnetic storms, which occurred during the formation, strengthening and the unexpected path-of-motion of Hurricane Irma.

d. The peak solar flare and SEP effects at Earth occurred from September 11-13, 2017, with Hurricane Maria forming just three days later on September 16th.



Kp8 Geomagnetic Storm (NOAA)

e. **A paper confirming the solar forcing of these cyclones was recently published (Vyklyuk et al. 2019)**. After September 2017, the sun went quiet yet again, and the tropical storm activity was largely lackluster until May 2018.



f. May 2018: The next solar flares produced no geomagnetic storms, but recall the rare double-cyclone formation near Yemen described earlier in this section, along with the major flooding in Maryland. This was that solar flaring uptick we examined in relation to those previous Yemen events.

g. Early July 2018: An unexpected flurry of sunspots, filament eruptions, and small solar flares occurred as Hurricane Beryl broke records in the Atlantic, and Category 4 Typhoon Maria spun in the west Pacific while a completely unconnected storm system shattered rain records in Japan. During this time, Tropical Storm Chris formed in cooler-than-expected waters off the Carolina coast.

h. In 2019 and early 2020 (publication date of this manuscript) there were virtually no sunspots, let alone solar flares or large CMEs.

Prior to the confirmation of the September 2017 cyclone forcing (Vyklyuk et al. 2019) their model claimed to be able to predict ~25% of hurricanes based on solar storm activity (Vyklyuk et al. 2016). They were spot-on in 2017.

For a three-year stretch, many storm records were broken and each during those upticks in solar activity. Consider that we did not mention them all, like the record number of super-typhoons in the northern hemisphere overall in 2015, the record activity of the 2015 season in general, a record far-eastern Hurricane Fred, and others that also occurred in concert with short-term space weather events and the high geomagnetic activity of 2015.

From mid-2015 to early-2020, nearly every significant space weather event caused record breaking tropical cyclone activity.

7) Concluding Notes on Storm Forcing by the Sun

Some other recent examples of clear storm forcing in the last decade:

a. In early November 2013, a powerful X-class solar flare erupted, surged electric currents through Earth's atmosphere, and within days Typhoon Haiyan became one of the most powerful west Pacific typhoons on record.

b. October 20-23, 2012: a major uptick in solar activity occurred during a late-season Hurricane Sandy, which became the largest gale diameter Atlantic hurricane on record during that solar uptick before hitting the East Coast of the United States.

c. It is possible to understand the finer aspects of the sun-cyclone relationship by examining the type of space weather in play and the details of the meteorological phenomena that occur thereafter. Let's compare the late June 2015 and Yemen 2015 events: The "6 Pacific cyclones" event in June 2015 occurred when the entire sun was active with CMEs, solar flares from multiple sunspots, and a coronal hole stream affecting Earth. **There were many sources of space weather at once... many cyclones at once.** The November 2015 Yemen storms (and May 2018 Yemen storms) each developed in the exact same location and took nearly the exact same tracks. The solar flaring that occurred during that period was from the same sunspot in each occasion. **Solar flares from the same sunspot… rare cyclones a few days apart, in the same location on Earth.**

Author's Note: The ability of sharp upticks in solar activity (from low activity) to affect cyclone activity probably spans the wave, particle and induction forcing pathways. At solar maximum an M-class flare means very little, but a strong C class event during solar minimum can offer 100x the wave energy at the X-ray level and deliver a 25-200 % change in key solar wind and geomagnetic induction parameters. For this reason, it is vital that we look less for the magnitude of the space weather events, and more for a large change relative to the background activity of the previous hours, days, weeks, etc.

Don't ask "How big would it have to be?"
Ask "How large of a change in activity are we seeing?"

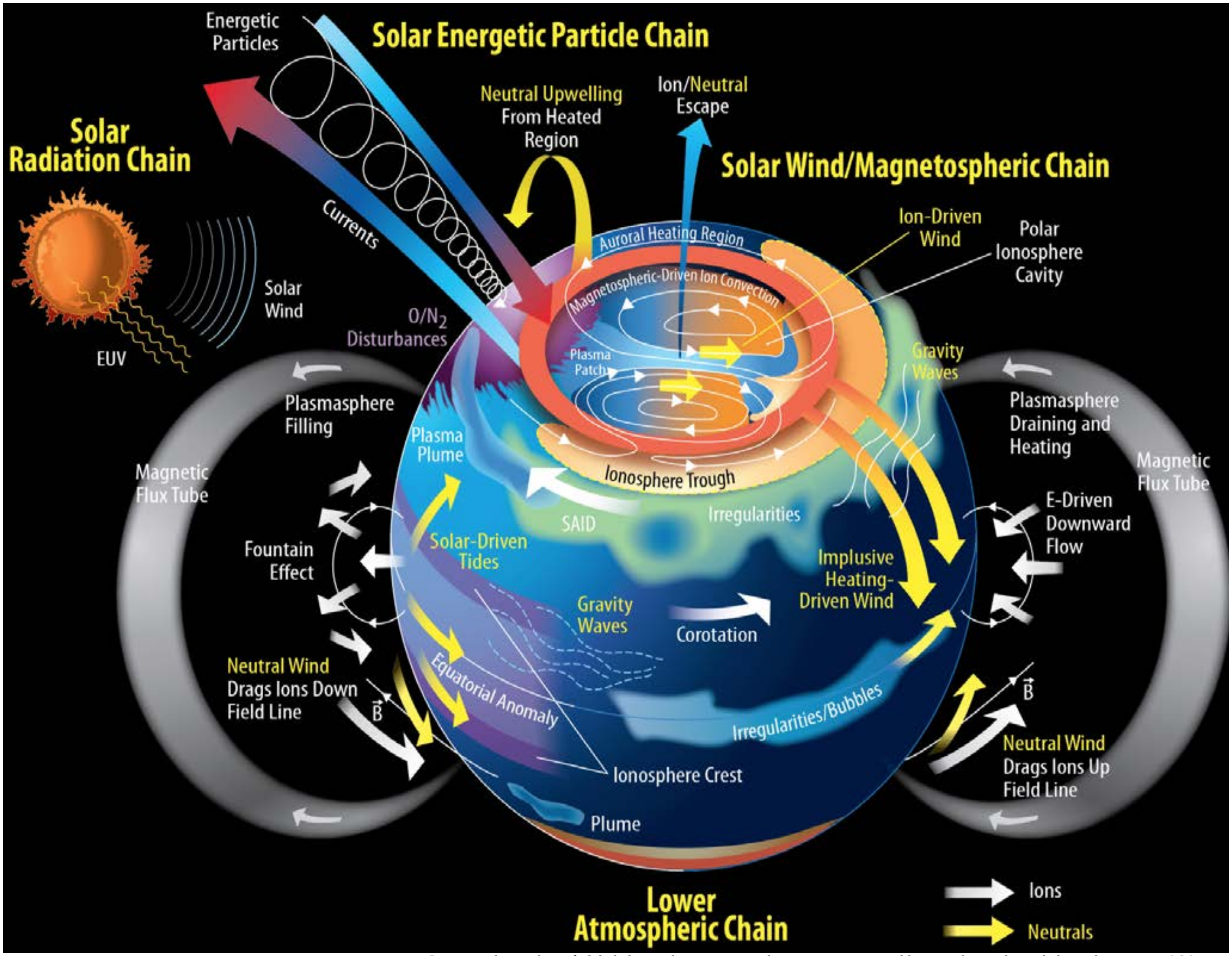
Key Points:

1) Lightning strike rates are likely modulated by the particle energy of space weather (GCR, SEP, magnetospheric electrons), with both high and low extremes of solar activity allowing for modulation.

2) In general ,solar minimum (more GCR) leads to higher long-term lightning rates, but sharp modulation over the short term is seen during strong solar events in sunspot maximum.

3) An overwhelming amount of literature and observable evidence exists for tropical storm development and intensification being driven by high solar activity, especially when it represents a sharp change in energy delivered to the Earth-system.

4) The source(s) of space weather can tell us when and how many Earthly storm effects may be seen (Yemen events from one sunspot vs many solar events and 6 Pacific cyclones).



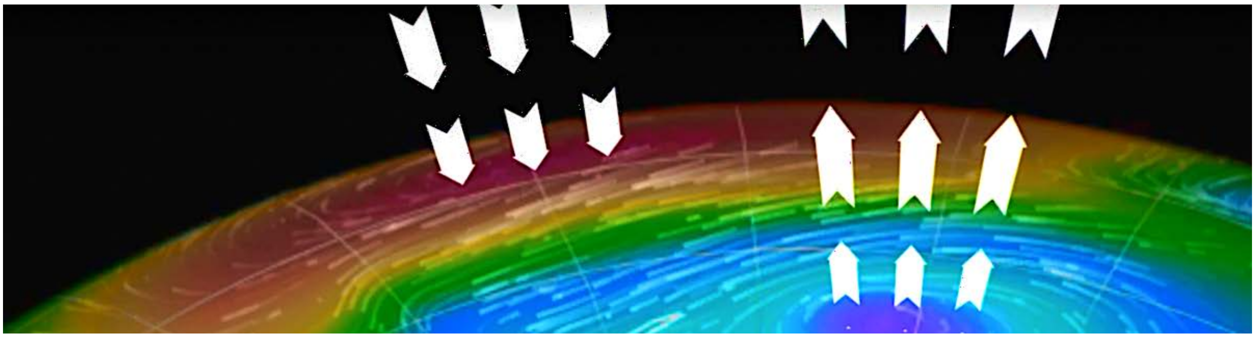
Current understanding of global electrical processes involving space energy and large-scale geophysical electrodynamics. NASA.gov

5.4 The Global Electric Circuit (GEC) Model

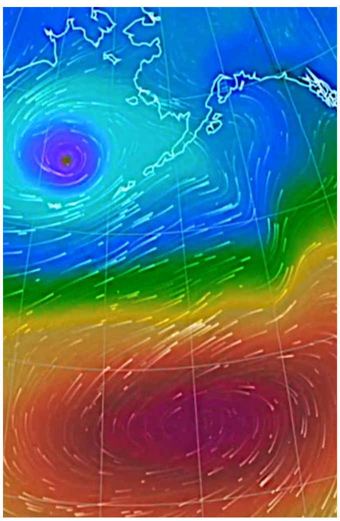
Everything so far has led to this. Electromagnetic particles and waves, Earth's magnetic field and ionosphere, induction and coupling- all at work throughout the atmosphere. We have learned that the total vertical column of the atmosphere is reactive to solar wind changes, now we will see why.

To this point we have mostly seen statistical correlations and mechanistic hypotheses based on good electromagnetic science, but the dynamics and mechanisms of action on small scales must be critically understood if you hope to be able to apply solar data and atmospheric electricity to your job, life, etc. The global electric circuit is the only explanation for the rapid total-atmosphere forcing of space weather.

The specific action of the charge and current in our atmosphere is described by the global electric circuit (GEC). In the next image we see the GEC in the lower atmosphere. The image is not to scale so that the general up/down effects can easily be seen. Red is high pressure in this image and purple is low pressure, with rainbow gradient.



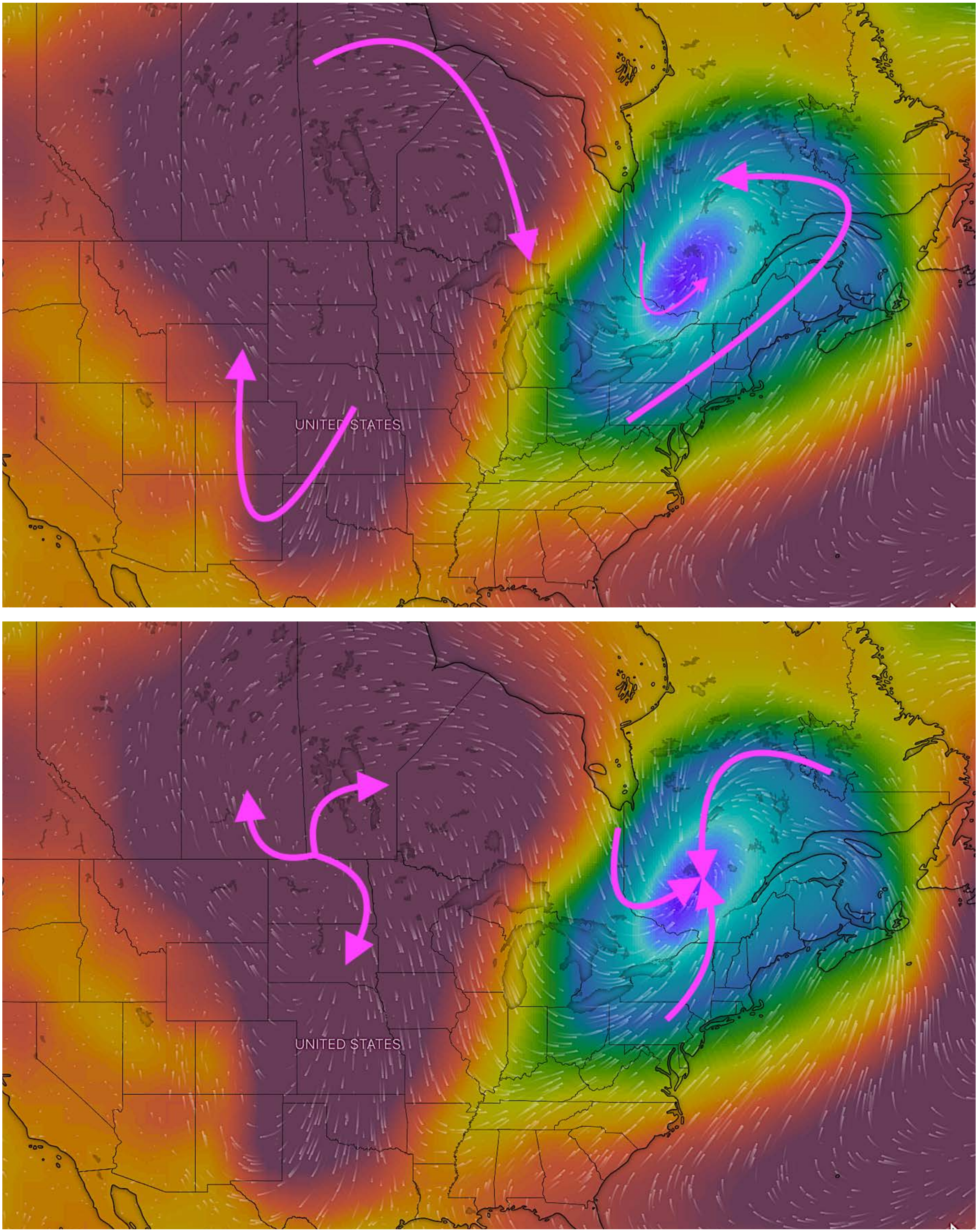
High Pressure - Current Downward **Low Pressure - Current Upward**



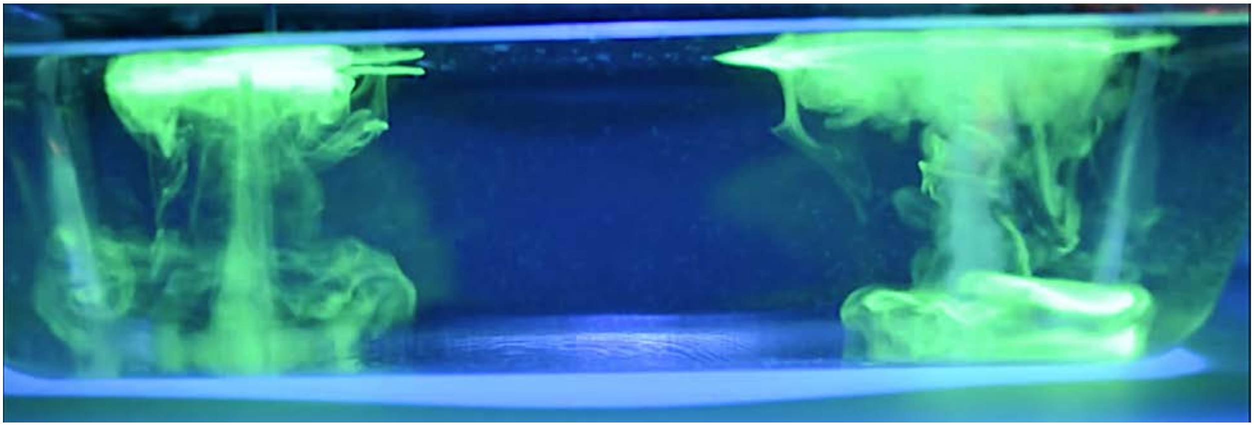
The up and down is not quite so simple: in the image on the left we see the same pressure cells as in the image above. Whereas the previous image showed the up/down GEC current in lows/highs, respectively, this image looks from above at the rotation of the air.

In these wind-vector images, the wind is shown as white dots with fading white trails behind them. Imagine them like points of white fire with trailing smoke behind them as they move; almost like dozens of little white comets with tails. With this in mind, we see that the high-pressure cell (red) has uniform clockwise rotation when viewed from above, and the low pressure (purple) has counterclockwise rotation.

The current is coming down from the ionosphere in the high, travelling to the low with the wind, and returning to the sky. When you combine the profile and top-down views, it is clear that the current moves in columns, and in a helical, spiral, vortex pattern.

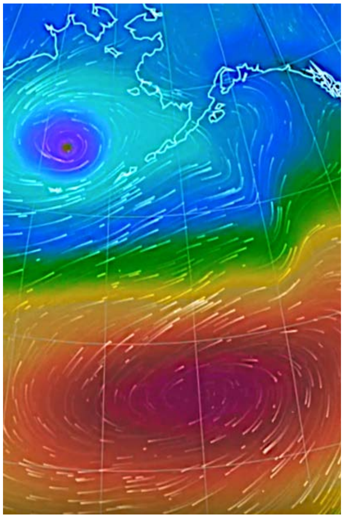


Pink arrows show macro-scale rotation of cells (top) and the outward push of the highs/inward pull of the lows (bottom). These are surface air flows, so where is the air coming from in highs – and where is it going in lows? The answer to both questions is *the atmosphere above*.



We can consider the rotational action from the profile view as well. The image above is from an experiment performed by Billy Yelverton Jr. in the Yelverton Lab (SpaceWeatherNews), and it shows a water enclosure with highlighter fluid added to show the motion of the water. In the centers of the columns of fluorescence are electrodes (anode and cathode) meant to carry current down into the water and then back out, simulating the GEC in a water vapor atmosphere.

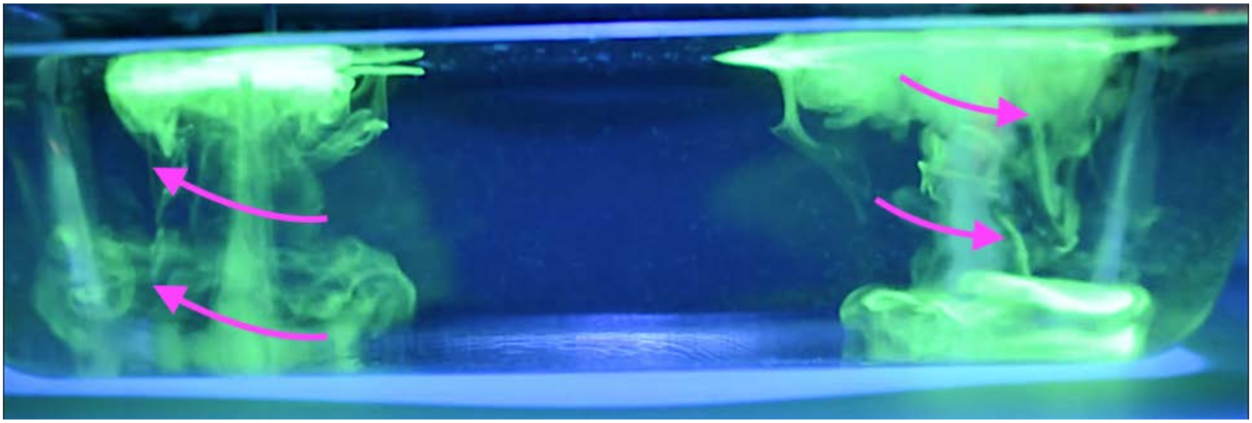
> *On the right side:* Current is coming down into the water, so we see the brightest density near the bottom, along with more compression, mirroring high pressure in the atmosphere and the expected action of the water under electric current.
>
> *On the left side:* Current is coming back up out of the water, and we see the bright, denser action at the top, just like Earth's air rises up through low pressure columns.



The columnar flows were rotational for both electrodes, and oppositely rotating at each column, similar to Earth's pressure cells. In the pressure image from the previous page (left) we can see that the wind forcing direction is the same between the high and low, to the northeast, which is where the current transfer occurs.

This matched-flow in the center was also present in Yelverton's experiment, where both column rotations came toward the camera on the inside (between the electrodes) and approached the distant-side of the enclosure, away from the camera, as they rotated around the outside of the electrodes to the left and right.

More information on electric current and water motion is coming in Chapter 7.



1) The Structure of the Global Electric Circuit (GEC) Flow

If the up/down columns of the GEC are found at the pressure cells, what is the roof and what is the floor? The roof is an easy one: the ionosphere. This is why space weather has a direct relationship with the entire atmosphere- it has direct electromagnetic access to the atmospheric GEC. Zhou et al. (2018) found that ionospheric parameters directly affect surface pressure because of this access, and it is why the total column is responsive to space weather.

The floor is a bit trickier. Some of the current will not come down through much of the stratosphere, or it will directly deposit into clouds. Sometimes the current will quickly funnel into a thunderstorm or cyclone near surface level after coming down through high pressure. Sometimes this current reaches the ground and below (Chapter 7).

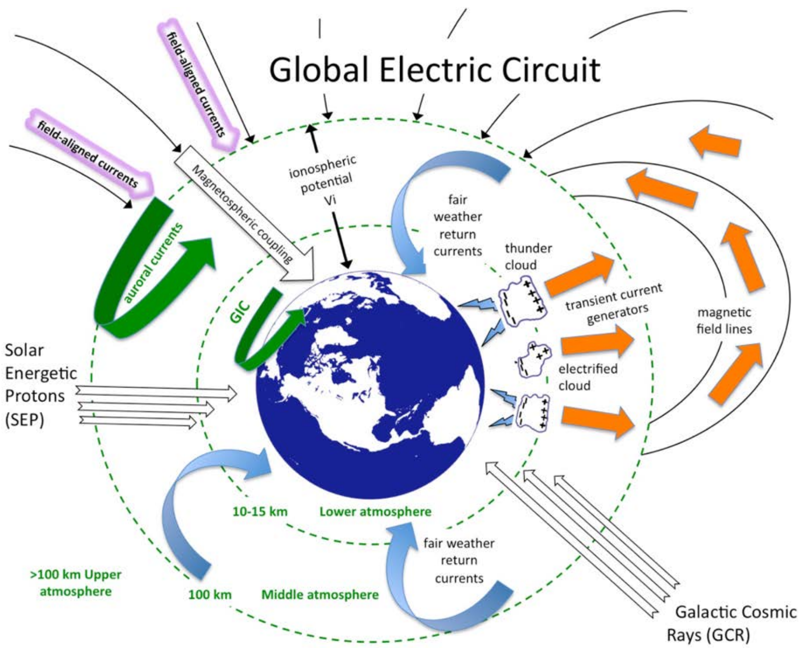


Image: NSF.gov

2) The History of the Field

> *Atmospheric electrical processes may help explain statistical findings indicating that variable solar activity, such as solar flares or the Earth's position in the extended solar magnetic field, affects the weather. An atmospheric electrical mechanism bypasses difficulties associated with solar heating mechanisms. Understanding Sun–weather relationships offers a basis for long range weather forecasting.*

- Opening paragraph from *Solar Modulation of Atmospheric Electrification and Possible Implications for the Sun-weather Relationship*, by Ralph Markson (MIT) 1978.

The entire paragraph is nice, but the key sentence is this: "*An atmospheric electrical mechanism bypasses difficulties associated with solar heating mechanisms*." This is where the field must focus. When it comes to the sun, cyclones, hurricanes and typhoons, there is an incredible and unfathomable resistance to this concept (despite the flurry of recent papers on the topic).

a. In 2000, Dr. Brian Tinsley (University of Texas, Dallas) suggested there were three main ways in which the solar wind affects the global electric circuit: cosmic ray modulation, high-energy electron precipitation from the magnetosphere, and magnetosphere-ionosphere coupling in the polar regions (Tinsley 2000). **Dr. Tinsley was two decades ahead of his time!**

b. In a comprehensive review, Siingh et al. (2007) identified solar flares and solar wind modulation to be the controlling force over the GEC.

c. During strong solar flares the electron temperature in the ionosphere was found to rise 28 - 92%, and ion temperature increased 18 - 39% (Sharma et al. 2011). These interact with the particles exchanged in the global electric circuit (GEC), and their effects are not currently included in climate modeling.

d. Other effects can be more subtle; Lynn et al. (2008) confirmed a previous finding that a CME impact triggered a wave and reverberation in ionospheric height of 300 km travelling at more than a kilometer per second! Nobody on the ground noticed it, but it strongly affected the top layer of Earth's electric system.

e. Williams and Mareev (2013) found evidence of transient excitation of lightning by gamma rays from cosmic ray cascades. This pointed to the cloud microphysical effects and ionization via GCR modulation over the solar cycle, up to a 25% variation in ionospheric potential. They also found this to be the same level of variation in one strong space weather event, meaning that one solar flare can trigger alterations of the energetic environment as much as is expected over an 11-year sunspot cycle.

3) The Current State of the Field

a. The primary space weather mode of action in the short term is an effect on the downward current density of the GEC, (Lam and Tinsley 2015), which agrees with recent studies on the solar modulation of the weather via atmospheric electricity potential gradient (Silva and Lopes 2017) and microphysical cloud electrodynamics (Regi et al. 2017), and which is implied in the literature addressing GCRs, SEP, magnetospheric electrons and others, such as interactions with Rossby waves and other planetary waves. (Kumar et al. 2017; Rycroft et al. 2012).

b. The vertical GEC current can be enhanced by CME impact and precipitating Earth-electrons, which produce channels of electric current ~8 km wide, from the ionosphere to the atmosphere, under high pressure fair-weather conditions (Borovsky 2017). These would be peripheral/secondary to the center of action of the cell, which would presumably have a much larger column.

c. In Antarctica (especially in winter) space weather modulation of the GEC controls surface pressure and temperatures (Lam et al. 2018; Lam et al. 2017) and there is evidence that this electric surface coupling applies to lower latitudes as well (Morozov 2018).

d. Researchers have begun to seriously investigate the specific connections between the GEC and the weather, like Lavigne et al. (2017), which found a correlation between GEC parameters and global precipitation, or Zhou et al. (2018), which tied the top GEC conditions to surface (bottom) pressure. Studies like these, and ones related to lightning, cyclones, and hail, are the future of the field.

e. The skyward current can be driven and accelerated by lightning events (Odzimek et al. 2018) and thousands of observations of high-energy current returns called lightning sprites have been made by photographers, amateur astronomers and astronauts aboard the International Space Station.

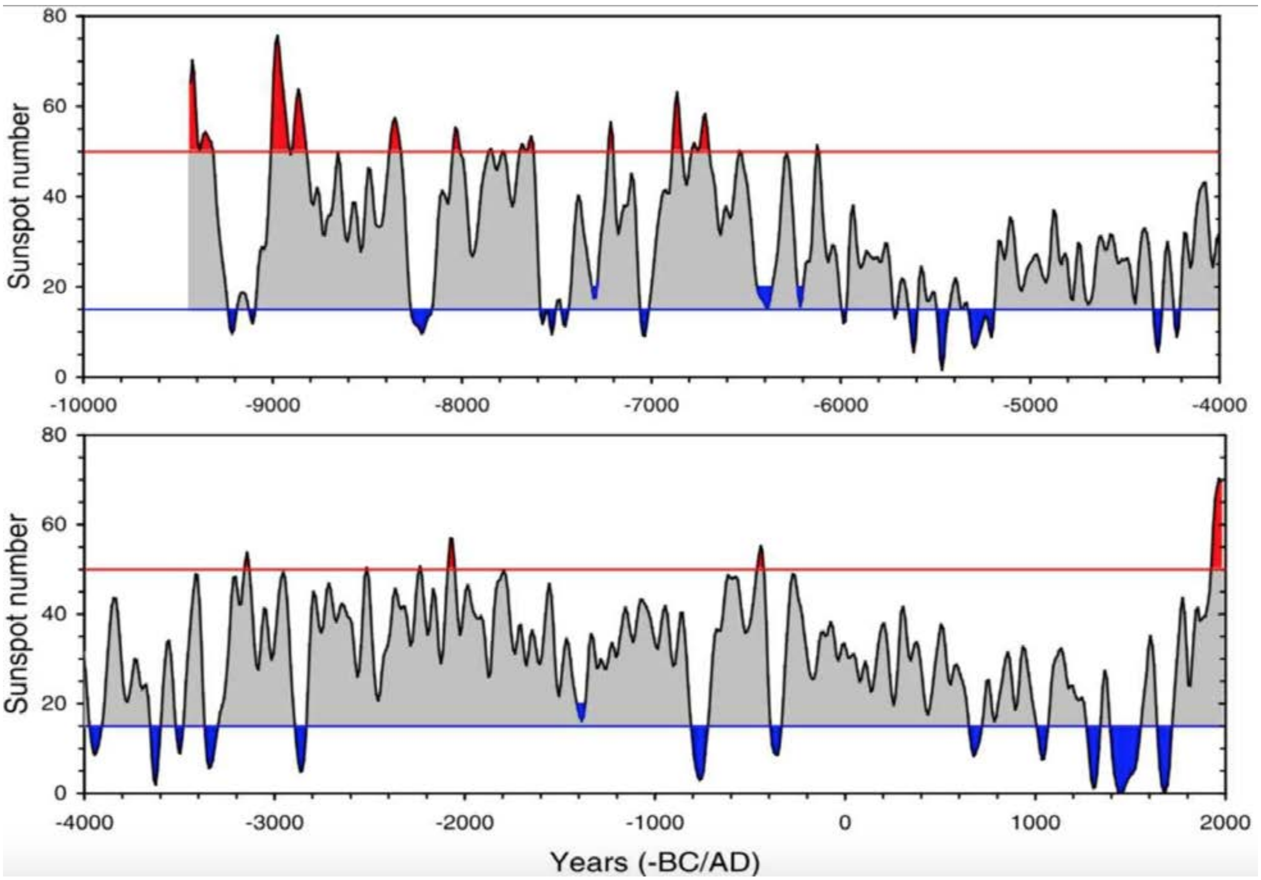
f. Ground-accumulated GEC energy is stirred back into the atmospheric circuit by cumulonimbus and other high-conductivity cloud electrical interactions with the ground (Mareev et al. 2019; Nagorskiy et al. 2019[1]; Nagorskiy et al. 2019[2]; Pustovalov and Nagorskiy, 2018).

g. Recent studies are solidifying the space weather effect on atmospheric electricity and the global electric circuit over short timescales, affecting clouds, storms, lightning, pressure, precipitation and temperature (Lee et al. 2019; Nicoll et al. 2019; Salminen et al. 2019; Zhang et al. 2019; Alimaganbetov and Streltsov 2018; Frederick and Tinsley 2018; Lam et al. 2018; Zhang et al. 2018).

h. Beyond particle and geomagnetic forcing, solar flaring has shown tremendous and immediate influence throughout the ionosphere, reaching the D region and being able to affect the global electric circuit (Li et al. 2019)**. This type of forcing is not able to be captured in TSI and SSI measurements, the ones showing a negative forcing during those same strong solar flare events and does not even begin address the particle forcing associated with it.**

Virtually nothing about the climate, weather, or solar forcing is untouched by the GEC. So, we must begin to critically re-evaluate the current climate change attribution paradigm.

SUNSPOT RECONSTRUCTION BY I. USOSKIN



When it comes to the modern warming of Earth, the sun delivered higher energy levels over the late 1900s than perhaps during any period in the last 12,000 years (image above, I. Usoskin), and Earth’s magnetosphere strength has begun to weaken rapidly of late, allowing a better connection with space weather from the top of the sky to the ground, and providing a scientifically practical (and increasingly significant) connection with the electromagnetic space weather events.

According to NASA and the ESA, the magnetosphere lost 10% of its strength from the 1800s to 2000; that number jumped up to 15% in 2010. While no new “% lost” figure has been given since that time, the 2015 ESA SWARM update reported a continuing trend of the magnetic changes, but

were otherwise non-specific as to what that meant. This field reduction is concurrent with an abnormal shift in Earth's magnetic poles. This geomagnetic reduction leaves Earth more vulnerable to the forcing we've discussed so far, both the thermal and electromagnetic couplings. During the time of global warming we had millennial-scale super grand solar maximum while Earth's magnetospheric protection from solar energy was weakening.

Key Points:

1) Space weather directly affects the ionosphere, and magnetospheric dynamics can indirectly affect the ionosphere. The ionosphere has a direct electric connection to and from the ground, through the atmosphere.

2) The GEC current is helical, coming down onto high pressure cells and returning to the ionosphere in lows. This is space weather's short-term access to the lower atmosphere, and it explains the total column changes and concurrent fluctuations in atmospheric potential energy and physical characteristics.

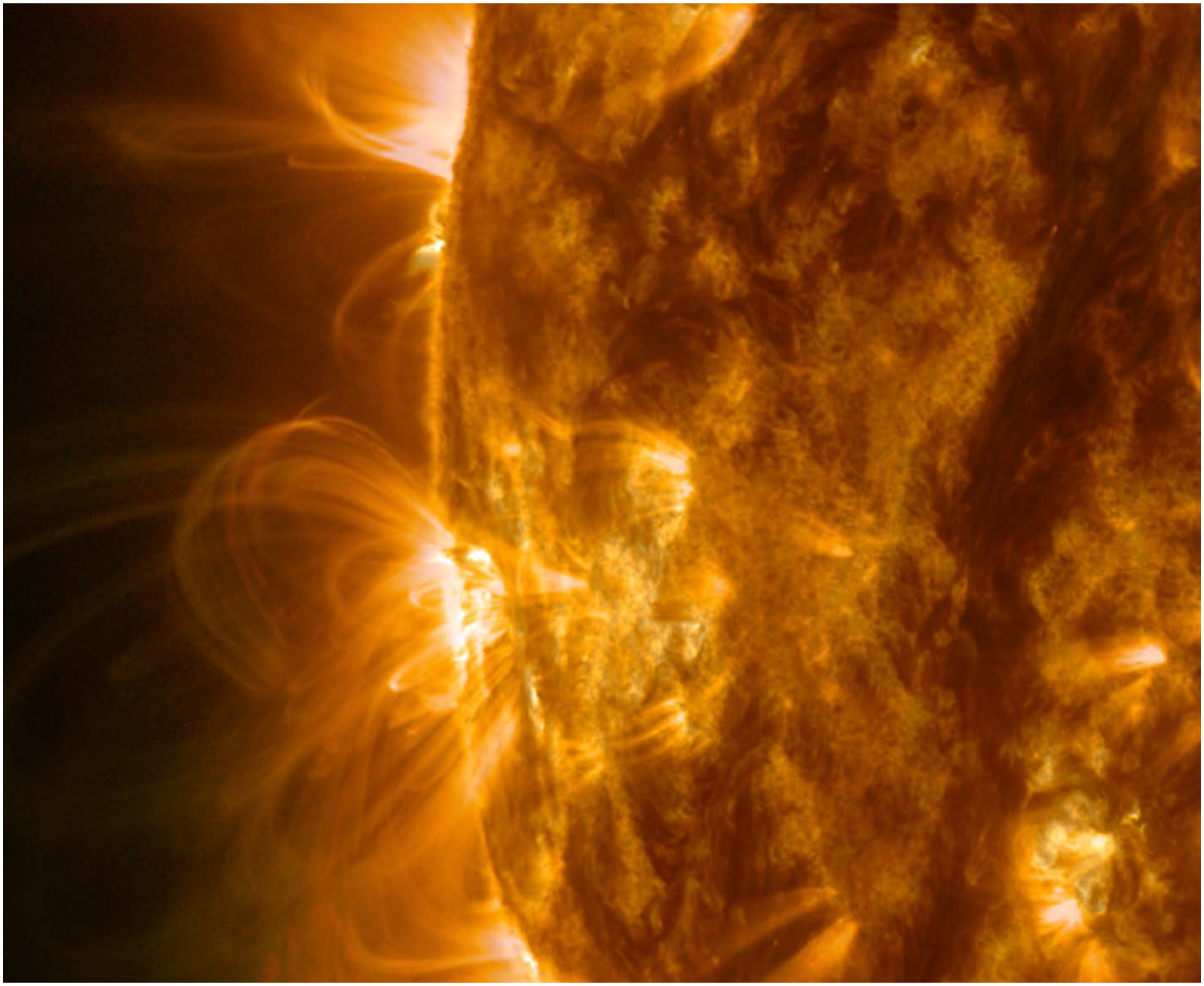
3) Earth's atmosphere is heavily composed of water vapor, which is a polar molecule attracted to electric current. The wind follows the global electric circuit.

4) The GEC allows electromagnetic energy from space to bypass the slow thermal coupling through the atmospheric layers, and interact with the troposphere in ways that affect pressure, circulation, ionization, clouds, etc. on short timescales.

5) The GEC takes a broad, chaotic energy influx from space and imparts order upon it, allowing it to be focused into a planetary circuit.

6) There are few aspects of solar forcing covered in this book that would not require the involvement of the GEC, and few aspects of the climate and weather that are likewise independent of the GEC.

7) Strong thunderstorms also return currents to the ionosphere, and can even stir the ground-accumulated current to re-enter the atmospheric circuit.


SDO/AIA 304/171

The plasma arches connecting positive to negative sunspots are similar to the GEC connection between high and low pressure cells.

5.5 Solar Forcing Scenarios: Space Weather, Physical Mechanism and Outcome

While the solar cycles of 11 and 22 years appear to modulate a great deal of the temperature, precipitation, pressure, and other atmospheric trends- the grand solar maxima, extended minima periods, and the short-term intense space weather events tend to provoke the most significant changes. While there is no golden rule when it comes to solar forcing over any time-scale, here are some practical guidelines that can aid in meteorological forecasting (and some of the tricks used by some of the priciest private companies to make their forecasts):

Scenario #1: A powerful (X5) solar flare erupts near the center of the sun and clearly releases a CME in Earth's direction.

a. When we see the flare, the x-ray energy is already ionizing the top of the sky and increasing the current in the global electric circuit (GEC). Within minutes, solar energetic protons (SEP) may begin the particle forcing of surface pressure at high latitude.

b. If the flare has occurred with active tropical storms in the day-light hours (facing the sun), expect them to intensify, and favor the models that hold the East/West track of the storm, as opposed to those taking the storms toward higher latitudes.

c. Upon CME impact, expect immediate intensification of sun-facing pressure cells due to increased GEC action- including tropical storms. Impact will add electron joule heating to the atmosphere. Expect a drop in global cloud fraction as the CME-driven Forbush decrease blocks out the nucleating/ionizing cosmic particles, with the exception of sun-facing (dayside) low pressure cells which will draw on that energy to intensify.

d. North Atlantic oscillation will trend positive for days beginning just after CME impact, usually during the onset of geomagnetic disruption.

e. The worst of the SEP event begins to dissipate during the geomagnetic storm phase, which is where the majority of direct proton particle heating of the atmosphere occurs. At the polar region, the rapid changes in pressure/temperature can be equivalent to seasonal-level shifts.

f. Sudden stratospheric warmings are more-likely to occur, and fewer/less-intense jet stream blocking events should be expected for days/weeks.

g. The storms that directly took the particle forcing from CME compression of the magnetosphere are likely to experience a localized, short-term increase in lightning, hail, and even tornadic activity- much like what can be expected at a global scale during the long-periods of sunspot minimum due to increased cosmic rays across the atmosphere.

Scenario #2: You are a meteorologist asked by your network to forecast the severity of the impending winter and the next summer flooding. What space weather information matters and what does it mean for you?

a. What is the current phase of the sunspot cycle?

   i. During the minimum and ascending phase of the sunspot cycle, after activity has been low for years, there is more chance of polar vortex weakening, which brings extreme cold and blizzard events, with the exception of Australia- one of the regions that sees the opposite effect (hot/dry) from polar vortex weakenings. You will have to expect more jet stream blocking in summer, driving larger temperature fluctuations and the potential for severe flooding – but also severe drought, depending on how this phase of the sunspot cycle affects your part of the world. The weaker Hadley Cell and Walker circulation will drive ENSO negative from the Pacific, creating a more equatorially confined tropical heat zone. During these periods, the NAO negative phase can combine with polar vortex weakenings to drive extreme winters in Europe.

   ii. During the maximum and descending phase of the sunspot cycle, expect the primary affects to result from the positive-phase-trend forcing of large scale oscillations, especially ENSO, SAM, NAO and QBO; after determining the sun's oscillation modulation, let the existing science do your job for your local area.

b. How strong was the previous sunspot cycle? How long/low was the last sunspot minimum?

   i. The decadal forcings are slightly weaker than the 1 to 4-year lags in forcing. When they sync up (in-phase forcing) it can provide for either extreme extremes, or extremely calm weather. The exception to the rule would be for severe summer storm events during sunspot maximum (decadal and annual forcing lags), which can be extremely severe, but which are not always driven by jet-stream blocking (latent heat release from the Earth's surface and short-term forcings from solar wind variation are involved).

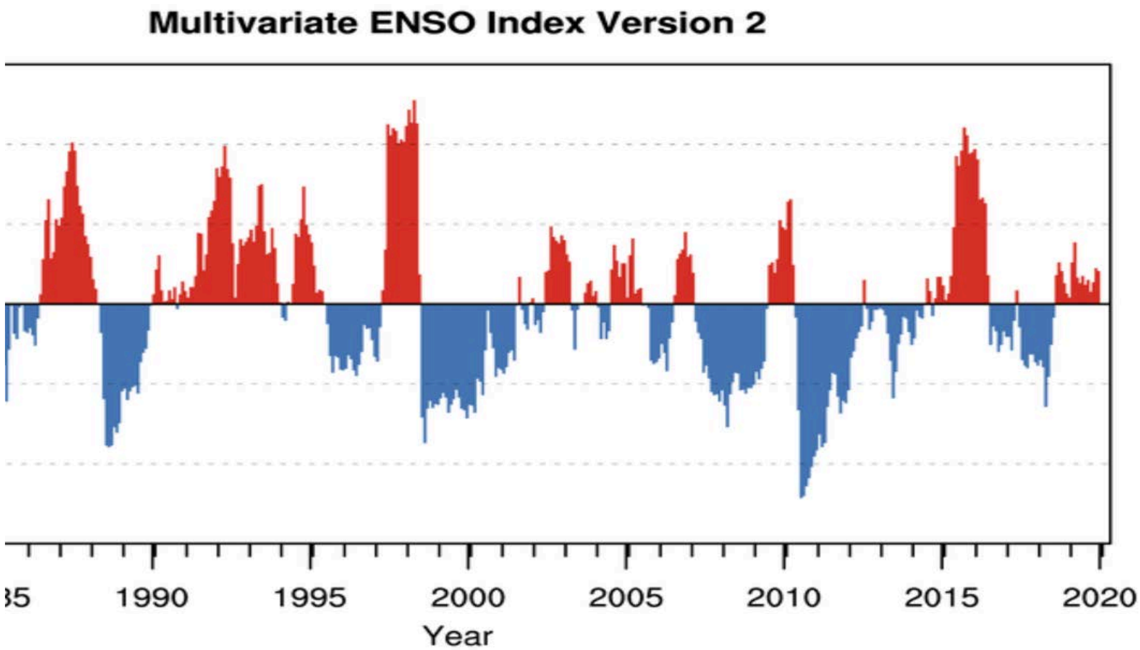
   ii. When decadal and 1 to 4-year lagged forcings are out of phase, the short-term forcings and muted 1 to 4-year lagged forcings are prevalent. In this case, you will unfortunately have to deliver a low specificity forecast WITH low certainty.

   iii. During periods of grand minimum solar activity (expected later this century) you will often have all oscillations forced negative, high cosmic ray cloud cooling, low solar particle/irradiance/induction heating, very weak large-scale cells, circulations, jets and vortices, and synchronized (in-phase) lags at annual and decadal scales.

Scenario #3: Your job is to forecast the ENSO cycle.

a. Solar forcing of ENSO is strong, but not phase controlling. So, if a solid El Niño is due, the presence of a deep sunspot minimum will not create La Niña conditions, but is more-likely to force a weaker El Niño than expected. When ENSO and solar forcing are in-phase together we get the strongest El Niños and La Niñas.

b. There is no short-term forcing of ENSO. The oceanic latent heat release is unable to be overridden by the Walker circulation boosts from solar activity if La Niña is in full swing, especially because the Walker and Hadley systems do not respond as rapidly as smaller scale atmospheric systems. When El Niño is in full swing, there are no rapid opposing forcing options; low solar activity is a slow bleed-out of energy, without the potential for rapid fluctuations downward like we have upward with high activity.



c. As of early 2020 the ENSO is positive but is considered to be in a relatively neutral phase.

   i. Natural multi-annual variability is favoring a negative phase in the next half-decade.

   ii. 2018-2020 was the low of this cycle sunspot minimum, following a weak maximum, which was following a long, low minimum.

   iii. “i.” and “ii.” indicate that natural variability (negative ENSO) is due to be in-phase with both annual and decadal negative-phase forcing from space weather. A very strong La Niña should appear between 2021 and 2025.

Scenario #4: Someone gives you the chance to state your case "against climate change science".

a. "This is not about denial OR pollution."

   i. Nothing in this book precludes the environmental impetus to protect our air, water and soil. We should all work to reduce waste and our use of toxic chemicals.

   ii. The blend of sciences is paramount to medicine, astronomy, technology, climate, and more, but it fails when one science overrules another based on emotion.

b. CO^2 is plant food, and food for the most critical elements of the marine food chain.

   i. The blame on CO^2 is confronted by the entirety of the studies in Chapters 4 and 5, but also by a shifting discourse in the scientific literature. In January 2020, it was announced that ozone depletion (not CO^2) is responsible for half of the Arctic warming, which accounts for 1/3 of all the global warming on Earth (image below). Meanwhile, greenhouses maintain CO^2 levels 3x – 4x the current atmosphere concentration.

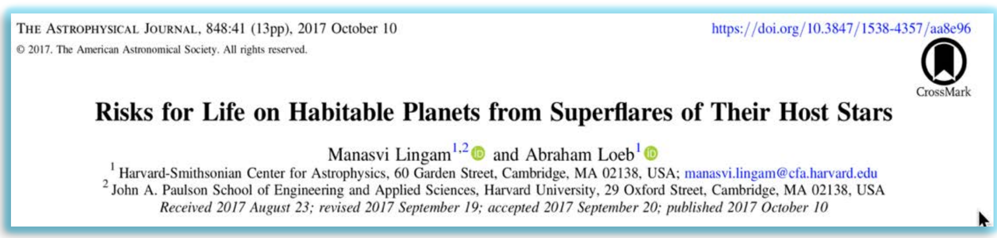
nature

NEWS · 20 JANUARY 2020

Ozone-depleting gases might have driven extreme Arctic warming

The far north is heating up twice as fast as the global average.

   ii. In addition to the open question of how much is left to blame on CO^2 after the broader role of the sun and ozone, we must remember that Earth's magnetic field is weakening. It has been repeatedly shown that higher solar particle input destroys ozone (including in the paper shown below) which results in considerable heating of the planet. This begs the question of how much ozone depletion is due to our chemicals vs the weakening of the magnetosphere allowing more solar protons into the atmosphere? This question has not been sufficiently studied; currently there are no answers, and certainly no certainty.



THE ASTROPHYSICAL JOURNAL, 848:41 (13pp), 2017 October 10 https://doi.org/10.3847/1538-4357/aa8e96

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Risks for Life on Habitable Planets from Superflares of Their Host Stars

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Received 2017 August 23; revised 2017 September 19; accepted 2017 September 20; published 2017 October 10

c. Scientists from NASA, and professors from Princeton, Harvard, Yale, Oxford, and hundreds of other top institutions are publishing on the topic of solar climate forcing, and yet they have been excluded from the discussion. While one arm of the climate world has held them at bay, the other waved a pamphlet to the rest of the world describing how certain they were about human-caused climate change. It is bad science. We can stop waste and pollution AND we can stop waiting for the correct science.

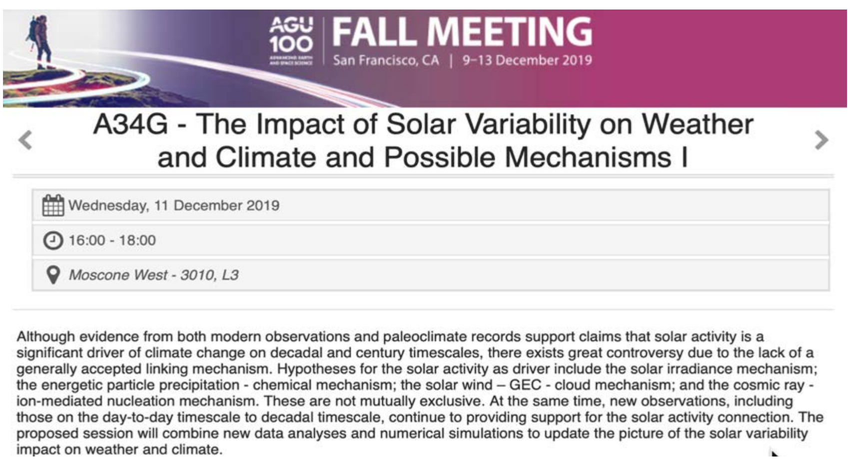
d. … Because the correct science IS already here:

   i. The United Nations (U.N.), World Meteorological Organization (WMO) and the International Panel on Climate Change (IPCC) have unanimously agreed to re-open the question of solar forcing after more than 40 years of its relegation to a small insignificant irradiance variability. New models for the 2022 releases will include cosmic rays and solar particles for the first time in any IPCC analysis.

   ii. They made the change due to the overwhelming flood of peer-reviewed literature, and due to new magnetic field and ionosphere data from NASA and ESA missions. There was simply no denying it anymore; they had to expand their view of Earth's relationship with the solar system.

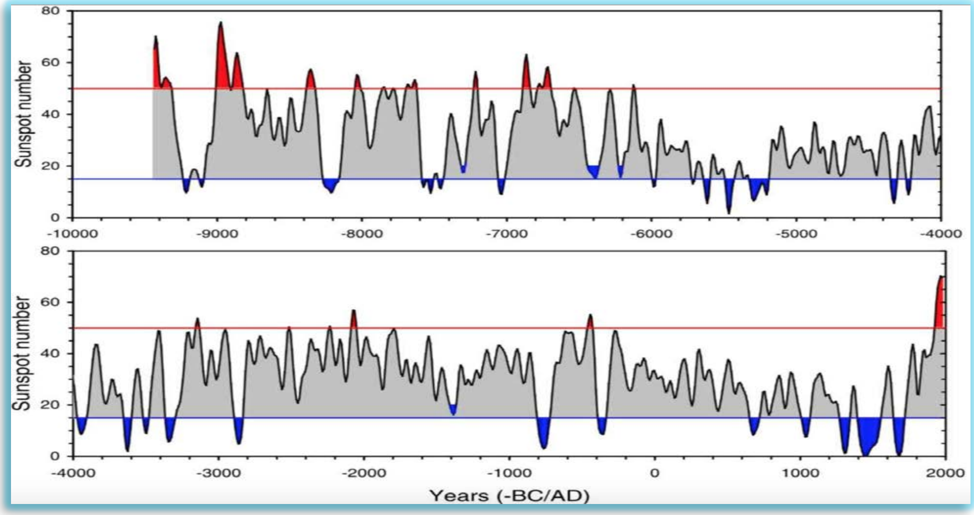
   iii. The climate "science" heard in popular media and from politicians is simply wrong according to the WMO, who pronounced it as a form of religious extremism, unrooted in scientific fact, and borders on terrorism in their demands of the world, occasionally under threat of violence. This is not only unscientific, it is uncivilized.

   iv. The #1 US Earth science group, the American Geophysical Union, which has published a large portion of the global warming papers in existence, dedicated a considerable portion of their prestigious AGU Fall Meeting 2019 to solar climate forcing. In the image below, you can read that they are focusing on solar wind, the GEC and cosmic rays.



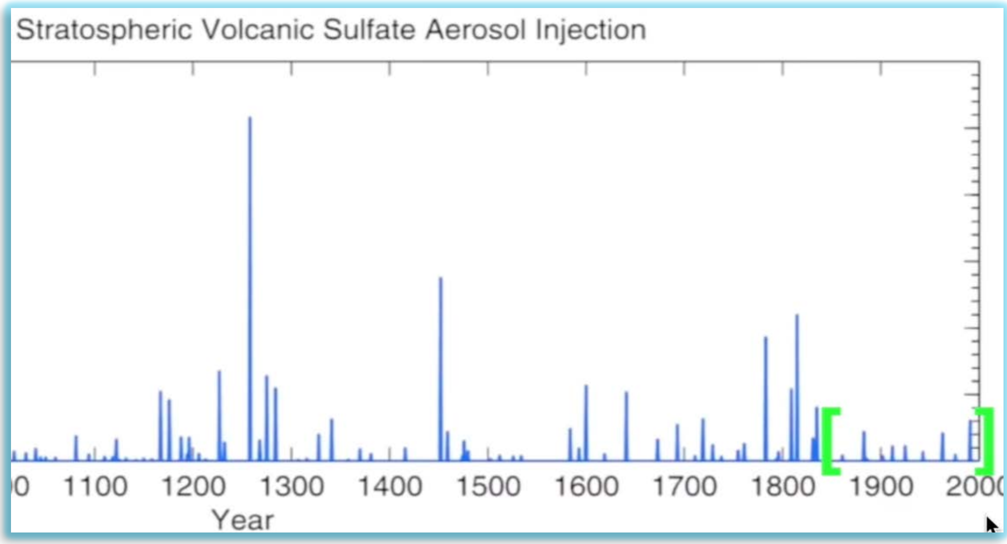
e. It took two extremes to get "global warming" where it is now.

i. Solar forcing was the highest in ~11K years, much higher than the previous 2000 years.



(Image: I.Usoskin, Sunspot Reconstruction)

ii. Volcanic aerosol cooling has not been this low since the 1500s.



The green bracketed area in the image above is all that is used in the official climate models, which is puzzling, because the chart is on the NOAA.gov (USA) climate website.

iii. The strongest solar activity in thousands of years met the lowest volcanic cooling in hundreds of years, during the exact time of global warming, and all while Earth's magnetic field is weakening, allowing more solar particle forcing.

f. Final Facts to Make You Think

i. Since the solar particle and cosmic ray dataset was released in 2017, there have been many studies that have utilized it to better-demonstrate solar forcing and the mechanisms behind it. However, there have been ZERO papers published that show the "human-blame for warming" story while using that particle dataset- none.

ii. Both NASA and the IPCC advise that their projections are subject to incredible uncertainty. Scientists from the National Labs have begun to suggest the same- and they don't need grants or the good graces of some professor emeritus, they just go for the truth. One in particular found the errors to be so great, including potential unknown sources of error, that one cannot mathematically extract any anthropogenic (man-made) warming signal from the climate at all (image below).


ORIGINAL RESEARCH ARTICLE
Front. Earth Sci., 06 September 2019 | https://doi.org/10.3389/feart.2019.00223

Propagation of Error and the Reliability of Global Air Temperature Projections

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The uncertainties in cloud forcing (the same thing those Princeton scientists are working on) is over 100x greater than the alleged energy flux change per year looking at greenhouse gases; which is like saying "humans take us up by 1 every year, but we have an uncertainty of 100."

iii. A major recent review found the sun to be the dominant driver of climate on Earth, and found the modern warming to be nothing significant over long periods. This is why the climate change modelling only goes back to the 1800s. Before that, the story completely falls apart – and not by using volcanos or the sun, but simply by looking at temperature and CO^2. The new study covers a period of over 5000 years. (Lara et al. 2020).

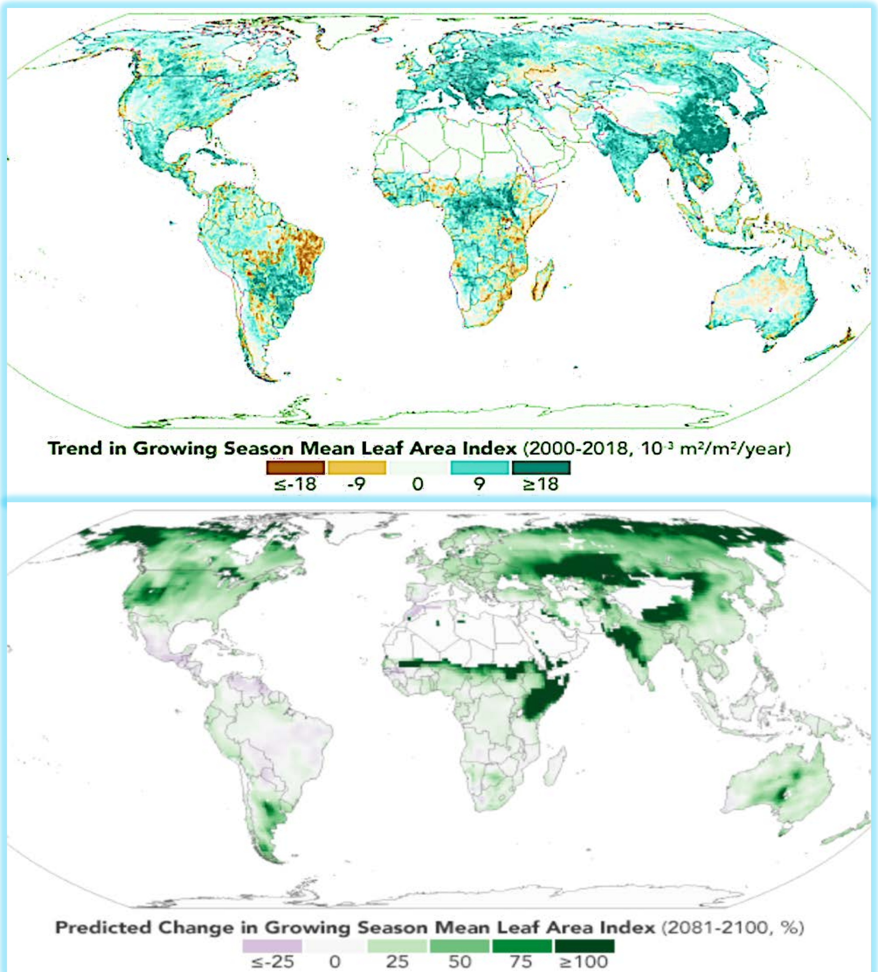
iv. The data handling method can result in up to an 18% difference in electron joule heating, while using the exact same data inputs (Zhu et al 2020). 18% may not sound like much, but in the world of "parts per million" and "fractions of a degree" in temperature, 18% is enormous. Furthermore, this is only addressing the electron precipitation, not the induced current heating or proton heating, which can deliver much more energy to the atmosphere than the electrons.

v. Will Happer (Professor Emeritus, Princeton), who is not involved in their recent cloud studies, but **was instrumental in creating the first climate models**, asserts that modern modeling is completely fictional, and does not at all accurately represent the

climate. These sentiments were mirrored by one of the world's top climate experts, Mototake Nakamura (U.Hawaii), in his recent work "Confessions of a Climate Scientist". If someone won't listen to you, maybe they will listen to Will and Mototake- two titans of the field.

vi. The new models (CMIP6) are already struggling to demonstrate the same story of climate change told for the last few decades. In one example, they modeled quadrupling CO_2 in the atmosphere, which is far beyond any realistic forecast of the future, and the only thing on which the models agreed was that there was virtually no change in near-surface response of the North Atlantic to sudden stratospheric warming events. The models disagree otherwise, and could not figure out if the sudden stratospheric warmings would be cut in half or doubled, revealing more of the uncertainties mentioned in item "ii." (Ayarzaguena et al. 2020).

vii. The planet keeps getting greener! It is well established that the planet underwent unprecedented greening from 1980 to 2000, and that trend has continued.



Images: NASA.gov, LandSat (Official Data/Forecast of 2020)

End of Scenario #4.

Miscellaneous Meteorological Forecasting Notes:

A major CME eruption from a non-Earth-directed heliographic longitude (side of the sun facing away from Earth) will present no flare and no geomagnetic impact. However, numerous examples exist in which Earth can still receive a SEP event and witness tropical storm forcing during those non-earth-directed falres/CMEs. They can which put a great amount of energy into the interplanetary field and plasma current sheet in every direction; watch the protons (SEP), even if the flare/CME explosion is aimed “the other way”.

When it comes to day-to-day or week-to-week forecasting, the sun should be considered a little push, or perhaps, a “tiebreaker”, unless there is major space weather at the time (X class flare, Kp7+ geomagnetic storm, etc.). For example, in periods where jet stream blocking events/polar vortex weakening events are “uncertain” in the forecast, solar maximum tips the scales for no blocking/weakening, and solar minimum tips the scales for blocking and weakening events. Either way, the short-term Kp index and X-ray flux should be used to gauge the current upper-level energy state.

When it’s your call and your models cannot decide what will happen, ask the sun.

6.0 Space Weather, Human Health and Technology

The atmosphere is not the only element of our world affected by space weather. This chapter details the known effects of electromagnetic energy on our health and technology. Starting with ourselves: Our bodies are full of that same conductive water as the atmosphere, our blood is full of conductive iron, our nervous system is a body-wide electric circuit, and the heart produces even more electric power than the brain- we are perfect candidates for electromagnetic effects from space weather.

1) We Start with the Heart

a. In a healthy person, heart rate and beat-interval fluctuations are correlated with space weather, with increases in both metrics during the most severe geomagnetic storms, and with high solar radio flux, high galactic cosmic rays (GCR), and variations of Schumann signals (Pishchalnikov et al. 2019; Singh et al. 2019; Stoupel 2019; Timofejeva et al. 2019; Alabdulgader et al. 2018; Galata et al. 2017; Mavromichalaki et al. 2012).

b. Healthy people also show significant, but often varying, responses to space weather variability in capillary blood velocity and arterial pressure (Nasutaviciene et al. 2019; Pishchalnikov et al. 2019; Gurfinkel et al. 2018; Ozheredov et al. 2017).

Note that both the highest solar activity and high GCR (lowest solar activity) have effects - these are the space weather extreme ends of the scale.

c. When there is very low geomagnetic activity and a higher flux of cosmic rays, there is a higher incidence of acute myocardial infarctions, cerebral stroke (Stoupel et al. 2013), and deadly arrhythmia (Kiznys and Vencloviene 2018; Ebrill et al. 2016), especially in patients with left ventricular dysfunction and ischemic cardiomyopathy (Stoupel et al. 2008). Geomagnetic fluctuations from high solar activity have also been shown to influence acute myocardial infarction rates on weekly timescales (Jarusevicius et al. 2018).

d. There is evidence for a correlation between arrhythmias and polarity reversals in the solar polar fields (Mavromichalaki et al. 2016) and during sharp Phi angle changes (Kiznys and Vencloviene 2018).

e. With the highest geomagnetic activity, there is a rise in the overall number of heart attacks, strokes, and sudden cardiac deaths of all kinds (Stoupel 2019; Zilli Vieira et al. 2019; Dimitrova et al. 2017; Vencloviene et al. 2016 [1]; Feigin et al. 2014; Stoupel et al. 2006).

f. During the days of lowest geomagnetic activity there is also a spike in total sudden cardiac deaths (Stoupel 2019; Dimitrova et al. 2017; Stoupel et al. 2016, Stoupel et al. 2013).

g. For patients with diabetes, or other metabolic disorders, high geomagnetic activity, especially from high-speed coronal holes, creates an increased risk of acute coronary syndrome (Kiznys et al. 2020; Kiznys and Vencloviene 2018; Vencloviene et al. 2016 [2]).

h. Geomagnetic storms have been shown to significantly increase arterial pressure, leading to adverse cardiac events; even small changes in local magnetic fields can induce anxiety and restlessness that can affect arterial pressure (Nasutaviciene et al. 2019; Pishchalnikov et al. 2019; Vencloviene et al. 2018; Azcarate et al. 2016; Martinez-Breton and Mendoza, 2015; Babayev et al. 2012).

i. Apollo astronauts show increased occurrences of cardiovascular disease-related mortality, likely due to their increased exposure to GCR over long periods (Delp et al. 2016).

j. Vascular diseases have been tied to low dose radiation in laboratory settings designed to mimic GCR exposure (Tang and Loganovsky 2018).

k. At a chemical level, blood-troponin levels in those with acute cardiac events showed significant modulation by solar and GCR activity (Stoupel et al. 2018; Stoupel 2017).

2) The Modern Evolution of the Field

Much of what western science knows about space weather and human health is built on a fantastic literature-review now nearly 20 years old. Cherry (2002) reviewed much of the published papers available at that time, much of which was only available in Russian, and found many of the repeating patterns and correlations that have been reported and confirmed since then. His findings included:

a. Over longer timescales, variations in sunspot number correlate positively with suicide rates (with highest sunspot numbers), and negatively with pregnancy-induced hypertension.

b. Correlations with heart attacks and strokes can be seen over annual/decadal scales in addition to daily timeframes.

c. **Geomagnetic storms positively correlate with convulsive seizures**, loss of attention and memory, and with aviation incidents.

d. Ultra low geomagnetic activity (highest cosmic ray flux) seems to induce vivid dreaming, increased crime rates, more suicide events, work injuries, sports injuries, traffic accidents, and psychiatric admissions.

e. Both sunspot number and geomagnetic storms are positively correlated with mortality in general, and a drop in birth rate. The birth rate issue was recently revived from the cosmic ray side when it was shown that even low-dose ionizing radiation may induce congenital abnormalities (Tang and Loganovsky 2018).

There are many other significant but varying risks for the conditions of both low (KP0) and high (KP5+) geomagnetic activity, and many confirmations of the claims in Cherry (2002):

a. The susceptibility of biological life to geomagnetic disturbances appears to increase with fatigue as well as with known factors such as previous risk, lifestyle choice, and geomagnetic latitude (Nasutaviciene et al. 2019).

b. **Medical emergencies of all kinds increase on days with zero geomagnetic activity (Stoupel 2019; Stoupel et al. 2013).**

c. Autonomic nervous system rhythms have been shown to sync-up with geomagnetic activity (McCraty et al. 2017).

d. Solar-induced disruptions of normal daily geomagnetic variations can affect circadian rhythm (Krylov et al. 2019).

e. **For multiple sclerosis (MS) patients**, hospital admission rates increase dramatically in the weeks to months following the strongest geomagnetic storms, with a peak lagging seven to eight months behind the storms themselves (Papathanasopoulis et al. 2016). This long-term response has been confirmed (Sajedi and Abdollahi 2017). Onset of MS, even at the earliest stages of life, has been correlated with geomagnetic activity at Kp7+ (Samoylova et al. 2017).

f. Both high and low Kp extremes have been correlated with migraines, digestive issues, cognitive diminution, vision impairment, decreased melatonin levels, slower reaction times, mood fluctuations, effects on the waking and dreaming states of consciousness, and changes in EEG/ECG activity. (Sasonko et al. 2019; Parihar et al. 2018; Rozhkov et al. 2018; Shepherd et al. 2018; Parihar et al. 2016; Gok et al. 2014; Shuvy et al. 2014; Persinger 2011; Zenchenko 2011; Soroka 2008; Babayev and Allahverdiyeva 2007; Cherry 2002).

g. Suicide rate correlation with GCR activity has been confirmed (Gour and Soni 2016).

h. Many of the cognitive/psychological effects, including significant medical outcomes like suicide, make more sense given recent findings of increased anxiety induced by space weather (Perez et al. 2020; Kiffer et al. 2018).

i. Astronauts, pilots, and even the unlucky airline passenger on a bad space weather day could receive biologically relevant, or even cancer-causing doses of solar/cosmic radiation (Cucinotta et al. 2020; Tenishev et al. 2018; Phillips 2013).

j. Charged particle bombardment has been correlated with decreased or eliminated ability to recover from brain injuries and impairments to the hippocampus that may have otherwise been overcome (Cacao and Cucinotta 2016). This has been shown for neutral (neutron) radiation as well (Acharya et al. 2019).

k. Space weather extremes (high and low) appear to be well-correlated with worse-than-usual influenza pandemics (Qu 2016; Hayes 2010; Moan et al. 2009; Yeung 2006).

l. Gut microbiota have shown response to cosmic ray exposure (Raber et al. 2019).

m. Human happiness indices have been statistically correlated with a lack of solar activity (anticorrelated with sunspot number) (Kristoufek 2018).

n. It is worth noting that the Schumann effects from lightning and other space weather-induced frequencies can be positive or negative in terms of the mental, emotional, and physical effects, etc., and are largely dependent on the specific frequencies to which the resonance peaks shift during the event (Persinger 2011).

o. Extremely low frequency (ELF) exposure, like those from magnetosphere reverberation during geomagnetic storms, has been shown to cause DNA damage, cause inflammation, disrupt cellular reproductive processes, reduce immune function, slow wound healing, and influence behavioral and psychological activity (Lai 2019). Similar correlations have been suggested for ultra-low frequencies (ULF) (de Assis et al. 2019).

3) Effects on the Brain

Many of the cognitive dysfunctions associated with GCR exposure have been subsequently confirmed in forward-looking studies for Mars astronauts (Cucinotta et al. 2020; Hu et al. 2020; Kiffer et al. 2018; Parihar et al. 2018; Tang and Loganovsky 2018; Parihar et al. 2016).

There are significant biological reactions to both cosmic ray surges and intense solar storms; the least risky periods appear to be when the Kp index is between 2 and 4, representing an equilibrium, modest amount of geomagnetic activity, whereas the low and high end of the scale are considered 'extremes'. The "Kp = 2-4 safe-zone" applies to most space weather-health connections.

How does it work? In the same way that the sun and GCR have different mechanisms for affecting the weather, they have different ways of affecting our bodies.

a. Biological creatures are subject to the induced currents of geomagnetic storms and the reverberation frequencies of the global field at ground level. At the other extreme, GCR strikes will directly ionize whatever they hit.

b. One study detected a significant 12-hr lag in human psychological effect from geomagnetic variation (Joffe-Luiniene et al. 2019), possibly induced by a +2x reduction in theta (4 to 7.9 Hz) brain wave activity (Novik et al. 2019).

c. Geomagnetic induction of anxiety, restlessness, and abnormal behavior was shown in laboratory animals to overpower sedative drugs (Fournier 2019). These effects, including

increased excitability, have been tied to solar flares (irradiance) and geomagnetic (induction) activity (Mukhin et al. 2018).

d. Increased propensity for aggression and high-risk behavior trends have been noted with the application of low magnetic field frequencies like those associated with geomagnetic storms (Shepherd et al. 2019).

e. From a cognitive standpoint, a foundational study demonstrated that the same extremely low frequency (ELF) radio waves produced during severe geomagnetic storms can also disrupt the locus coeruleus, the part of the brain that directly modulates our ability to deal with stress and panic (Rostami et al. 2016). This can have direct effects on cognitive function and behavior. Correlations with ELF/ULF continued to confirm this pathway of modulation (de Assis et al. 2019; Lai 2019).

f. Meanwhile from a GCR standpoint, the most abundant particle bombardment (^{1}H) was shown to induce anxiety-like behaviors; postmortem analyses revealed stark hippocampal changes (Kiffer et al. 2018).

   i. This analysis held true for iron nuclei GCR as well, which come from supernova (Cacao and Cucinotta 2019; Dutta et al. 2018; Raber et al. 2016).

   ii. Similar cognitive deficits were seen with exposure to Helium nuclei (Raber et al. 2018).

   iii. Studies indicate that part of the neuronal damage may occur from increased oxidation processes triggered by protons, oxygen nuclei, carbon nuclei, silicon nuclei and iron nuclei (Cacao and Cucinotta 2019; Liu et al. 2019; Raber et al. 2019; Belov et al. 2016) and from decreased hippocampal cell division (Acharya et al. 2019; Sweet et al. 2014).

   iiii. Recent analyses also linked various cognitive defects to neuroinflammation and changes in gene/protein expression induced by cosmic rays, as well as neuronal function vulnerability (Cucinotta and Cacao 2019; Ueno et al. 2019; Parihar et al. 2018).

The image on the following page shows some space weather scales and health concerns; you will notice that the geomagnetic (Kp) index is ‘scary’ at both ends.

GEOMAGNETIC & COSMIC RAYS HEALTH RISKS

AT THE EXTREMES OF THE SCALE

Kp Index Score:

0 1 2 3 4 5 6 7 8 9

Cosmic Ray Risk* **S A F E Z O N E** **Geomagnetic Storms**

All Biological Life:

Increased Risk/Exacerbation of Seizure, Migraine, Cognitive Diminution, Melanin and Light-Based Disorders, Multiple Sclerosis, Auto-Immune Disorders (including Lupus, Arthritis, Epidermal/Glandular), Anxiety, Emotional Instability, Panic-Induction Activity in Locus Coeruleus*

High Risk Patients:

ALL Cardiac Risks Elevate During Geomagnetic & Cosmic Ray Events. Numerous Negative Mental Health Events are Associated with the Extremes of the Scale (Suicide, Hospitalizable Episodes of Depression, Anxiety, Bipolar disorder, Psychosis, etc.)

* Cosmic Ray events begin after ~12hrs of Kp=0 or ~24hrs of Kp<1
"Major" alerts occur at 24hrs of Kp=0 or 48hrs of KP<1
Alerts last ~24hrs after Kp Increase

Solar Proton Radiation Storm (SEP Event) Risks are the Same as for the Kp Index Extremes, Except That SEP Storms are Initiated by Solar Flares

~

SOLAR FLARE HEALTH RISKS

INTENSITY-BASED RISK

Solar Flare Index

A1 B1 C1 C5 M1 M5 X1 X5 X10 X20

"The Stronger The Flare, The Higher The Risk"

All Biological Life:

Increased Risk/Exacerbation of Seizure, Migraine, Visual Impairment, Reduced Cognition/Reaction Time, Melanin and Light-Based Disorders, Auto-Immune Disorders (including Lupus, Digestive, Glandular), Significant Anxiety/Depression Events

On the previous page, you can see that solar flares are magnitude based, with no concern at the low end of the scale, while geomagnetism is based on an equilibrium safe zone - you don't want too much, or too little. This information is utilized in our "Disaster Prediction App" - currently the only space weather health alert App on Earth.

Let us consider this equilibrium risk scale in a way that will help you understand a bit better. A need for balance should not be all that foreign of a concept when you consider how many things in this life are needed in balance; even too much water or oxygen is toxic. Another example is food: You need it to survive, but overeating-related deaths have overtaken starvation deaths worldwide in the last decade, representing the other side of the scale. It stands to reason that a similar biological optimum exists in electromagnetic energy/effects of space weather, where either extreme presents a risk.

Author's Notes: During a SEP event in 2013, it is estimated that a cancer-causing dose of radiation could have been received by a handful of the 1000s of airline passengers in the sky during that time. This was only a Level-2 SEP radiation storm. This information was released in a report about lack of radiation monitoring during the government shutdown of October that year. The report remained one of the few official US government acknowledgements that space weather presents any danger at all until October 2016 when President Obama issued an executive order on space weather, stating that it presented a significant risk to our technology and human health worldwide.

> At Level 3, the SEP event would have put dozens at risk. At Level 4, the storm would put thousands at risk. At Level 5, everyone in the sky would be at risk.

Looking ahead: Earth's weakening magnetosphere is allowing more energy to enter the Earth system now than in the last few millennia (at least), and these correlations from sky to ground are going to become more noticeable as you look down the road ahead. The September 2017 solar flares drove a Level 3 SEP event, and the primary CME missed Earth, along with its 2nd punch of protons, or we could have seen a very dangerous air-travel situation.

Whether you are taking to the skies, have an existing heart condition, diabetes, depression, or you engage in high-risk activities, space weather may play a role in your life. There is a tightrope walker who always checks-in before dangerous walks- he will not risk a cognitive or attentive diminution event if he is untethered 900 feet above a rocky ground. What if your co-worker isn't being annoying that day- there is a cosmic ray effect on your anxiety and emotions?

For those interested in keeping up with this field, you must also be on the lookout for non-space weather studies. The Rostami et al. 2016 study that correlated ELF with human brain problems was not at all about the sun- it simply looked at frequencies that happen to be known to be produced by the sun's effect on our magnetosphere. In another example of such a study, Letuta et al. 2017 determined that all enzymatic intracellular interactions involving electron transfer are actually a function of magnetoreception and can be affected by external magnetic fields. They surmised that something believed to be purely chemical is actually an electromagnetic process that can be affected by magnetic fields. They didn't mention the sun; they didn't need to.

Notes on Space Weather and Viruses:

Most of the correlations between virology and space weather are at the cosmic ray peaks over time, with many commenters suggestings that immunodeficient symptoms known to be associated with exposure to radiation or electromagnetic frequencies are logical explanations for why humans don't handle viruses as well during those times.

However, there have been clear examples of virus mutation or re-activation under enhanced electromagnetic environmental conditions, including Ebola, HPV, and influenza. While it is uncertain exactly *how* the cosmic energy re-activates viruses lying dormant within the body, and while there isn't much to be done about these facts, it is worth knowing that the re-activation combines with the increased mutational potential (due to that cosmic energy) and the immune depression to make for a multi-mechanism means of solar viral forcing.

Remember from earlier in this section: "Space weather extremes (high and low) appear to be well-correlated with worse-than-usual influenza pandemics (Qu 2016; Hayes 2010; Moan et al. 2009; Yeung 2006)."

More of the top articles on the topic:

Oncogene. 2003 Jul 17;22(29):4469-77.

UVB irradiation reduces the half-life and transactivation potential of the human papillomavirus 16 E2 protein.

Taylor ER[1], Boner W, Dornan ES, Corr EM, Morgan IM.

Geography · Published 2016 · DOI: 10.4172/2332-2519.1000154

Sunspot Activity, Influenza and Ebola Outbreak Connection

ELSEVIER

Medical Hypotheses

Volume 74, Issue 5, May 2010, Pages 831-834

Influenza pandemics, solar activity cycles, and vitamin D

Reactivation of Latent Epstein-Barr Virus: A Comparison after Exposure to Gamma, Proton, Carbon, and Iron Radiation

Int. J. Mol. Sci. **2018**, *19*(10), 2961; https://doi.org/10.3390/ijms19102961

DOI: 10.19080/IJCSMB.2018.04.555636

Weakened geomagnetic field, Cosmic rays & the Resurgence of Yellow Fever

Citation as in each image, gathered by Todd Cleckner.

Climatology & Weather Forecasting

Mukherjee, J Climatol Weather Forecasting 2014, 2:2
http://dx.doi.org/10.4172/2332-2594.1000113

Opinion Article — Open Access

Electron Flux and Cosmic Ray Anomaly Before H1N1 Outbreak

4) What To Do With Space Weather Health Information

There is only one wrong answer to the question of what to do about space weather health alerts: Spend time worrying about it whilst eagerly watching solar data and self-scanning to check if you "feel something." The correlations described in this book account for the modulation of unaware individuals. Psychosomatic effects are real, and if you watch for something and worry about it when it happens, it can manifest as something worse than it otherwise would have been.

This is a scientifically real medical phenomenon, but luckily it has an opposite, and equally powerful counterpart: the placebo effect. When it works against you, it is called the nocebo effect.

The placebo effect is the most magic thing humans do, and almost nobody recognizes it as such. Based on nothing but your thoughts, the rules of biology and chemistry are overpowered within your body to create an alternative outcome. That sounds like actual magic. Know that every person has this power, and it can be used in daily reminders, meditations, or on the spot mental notes as you smile at yourself in the mirror and know your body is capable of incredible things.

Otherwise, this information should be used cautiously, without fear or panic. While this book cannot hope to give medical advice, it can offer some common sense:

a. If you are a tight-rope walker, you do not feel so good one day, you are aware that a geomagnetic storm is occurring, and you know that cognition is affected during these events- then maybe you should stay home. Basically, don't beach yourself; gray whales are proven to beach themselves more-often during geomagnetic storms. (Granger et al. 2020).

b. If you survived a heart attack, have been prescribed baby aspirin but you do not take it, you are having chest pains, and then as you are wondering if you should finally listen to your doctor that day, you find that cosmic rays are extremely high- maybe you should finally listen to your doctor and take the medication.

Key Points:

1) Dozens of correlations between space weather and human health have been published, covering numerous conditions and bodily systems.

2) Both extremely high and low geomagnetic activity appear relevant for health effects, with the low end being dominated by higher GCR levels.

3) Heart attack, stroke, arrhythmia, blood pressure, heart-rate, blood-troponin levels, and more cardiac events/parameters are strongly linked with space weather extremes.

4) Cognitive, emotional and mental effects from space weather are correlated just as strongly as the biophysical effects.

5) Good candidates for pathways of psychological influence are through the locus coeruleus (geomagnetic frequencies) and hippocampus (cosmic rays).

6.2 Space Weather and Technology

If the human race existed at our current technological stage for 1000 years, with skylines similar to the one above, we would have seen this image at least once- aurora dancing above dark silhouettes. The silhouettes are dark because there is no electricity, which is the very-real global-scale concern from space weather.

When the auroral and equatorial electrojets are energized by space weather events, those upper-atmospheric flows induce electric currents in the atmosphere and the ground. These currents have been responsible for some of the technological disruptions we have seen while we await the next super solar storm, a major blast that occurs approximately every 100 - 300 years. We just happen to be lucky that the last one occurred at the early dawn of our electric age in 1859.

Major solar events have happened countless times in human history, but before now posed little threat to our way of life outside of the weather. It was mostly a beautiful light show in the sky (aurora). Today, we have an electric-dependent way of life, and even cultures that live simply have had vast changes to their economies, lifestyles, and ecosystems due to globalization's long reach; many simple cultures have found basic ways to be a part of the global system and have forgotten who they are in much of the same way as we have in more westernized cultures.

If we were to lose electricity on Earth for any meaningful period it would likely result in the end of modern civilization. When everything needs repaired, no vehicles are working, and no gas stations are operating, rebuilding becomes a major challenge. That is before you consider that the induced current would likely melt all the main copper wires. How do you reconnect them to even one city when you cannot get supplies to do so? Or the gas to get trucks to the lines, or equipment to put up the lines? Who manufactures the parts you need when they are all offline too?

For the rest of us- No ATM, no heat/AC, no water from the tap, no food at the store, no refrigeration, no phone… just you and everyone else.

1) Severe Solar Storms

In the modern electric age there have been a few notable space weather-induced technological disasters in the record:

a. The Carrington Event, a tremendous solar storm in 1859, set fire to telegraph wires and shocked operators. When they unplugged the machines, the messages kept coming in. Back then there wasn't much to destroy, and we have yet to see another such event come towards Earth. NASA estimates there could be weeks to months without power if it happened today, with $2 trillion in damage to infrastructure alone. This event likely happens once every 100 - 300 years, and so +161 years since the last one we are in the 'return period', and we carefully watch for such a flare every 11-yr sunspot cycle.

b. In ~775 AD a tremendous solar event seen in the ice-core isotope records, known as the Charlemagne event, was likely 3 - 10x stronger than the Carrington event, and there would be little chance to escape a worldwide grid collapse in such a scenario. This event is likely a once/1000-2000 years event. Today, 1250 years later, we are in the return period of this level storm as well.

c. In the space age, we have already seen satellites taken-out by solar storms, including the Sky Terra station, which was rendered useless during a 2012 storm. Once or twice every ~11-year cycle, a strong solar storm disrupts air travel or causes major power grid issues.

d. Before 2012, the last major event was a power grid failure in Sweden/Norway in 2003, and before that, we had significant damage to NOAA satellites in the early 1990s.

e. In 1989 a strong solar flare and CME caused a geomagnetic storm that took out power to the entire Canadian province of Quebec.

f. In the 1960s a major solar storm reduced radar capability near the Arctic. Thinking the Russians were jamming their signals, a full-scale attack was preparing (jets being prepared/pilots waking and dressing) to launch. It was lucky that word came in of space weather effects or the world may look different today. General Vanderham told this story at the 2017 National Space Weather Enterprise Forum in Washington D.C. He was trained by one of those pilots.

g. In 1921 the New York railroad was completely disabled due to electric surges during a powerful geomagnetic storm.

2) Modern Activity under the Weakening Magnetosphere

Approximately once or twice per solar cycle we have become accustomed to a major storm event occurring where there is significant technological failure. Then, in 2015 things began to change:

a. In three separate space weather events from June-November 2015, airspace over New Zealand, Sweden and the east coast of the United States was shut down during strong geomagnetic events. Causes included radar outages and large system shut-downs. These were the same solar events that triggered the weather records described in Chapter 5.

b. Strong geomagnetic storm activity occurred during the “grid shut-down” and “shed load” orders in southern California in September 2015 as higher voltage than was produced or capable of being handled by the system began surging through it. Millions were left without power. Another of the 2015 weather records was falling at this time.

c. Even slight geomagnetic disruptions tracked by SpaceWeatherNews.com throughout the rest of 2015 were accompanied by increases in reports of electrical and transformer fires, communications and transportation disruptions (such as the San Francisco BART electrical anomaly), and incidents at other digitally based systems. Over a 28-day period in October the Sony PlayStation Network went down every time a geomagnetic storm occurred.

d. In a throwback to 1921, and in investigating the 2015 train events, a recent study found that the railways have once-more become a dangerous place during geomagnetic storms, especially the high-speed rails now largely based on electromagnetism (Liu et al. 2016).

Let’s put this change into perspective:

> These types of technologically disruptive events are expected to be seen every few years to a decade apart. The flurry of electrical-malfunction/technological issues surged to life in 2015 in the same way that the weather records began falling at precipitous rates. It continued through 2016 until the absolute low of solar activity in 2018. The sun is expected to get active again in ~2020 - 2021. The activity on the sun from 2012-2016 was significantly weaker than in any other “sunspot maximum” of the space age, and yet there was still a surge in technological risk to space weather.

SOUND FAMILIAR? It was not just weather records that began falling during space weather events in 2015, the technological disruptions seemed to be occurring at record levels too.

The question implied is:

"Why so many technological events- especially with weaker space weather than in the past?"

Mainstream climate science blames CO^2 for the weather records in 2015- we blamed a weaker magnetosphere against space energy and the long-term solar activity. Let us apply that thinking to this situation, which follows the same event timeline and peculiar increase in severity in 2015:

This author submits that the scientifically-logical and temporal electromagnetic changes on Earth, which better-explain the recent record cyclones from a physics perspective, are an ***even more obvious*** explanation for the technological vulnerability that occurred at that same time. Either CO^2 somehow increases technological vulnerability to space weather, the technological uptick concurrent with the record-weather uptick is an amazing coincidence, OR we need another explanation for them both.

The Earth's magnetic field is on an increasingly rapid long-term decline, but it is not a smooth curve. It moves like the stock market, up and down, even through clear longer-term trends. 2015 was a "down" year; the last few have been a bit better. While on the field upswing here at Earth, the sun has been in the minimum of its sunspot phase for most of the time since 2015, but will enter 'solar maximum' again in 2020 – 2025, on the heels of another expected geomagnetic shift to the negative.

Information on the Earth's changing magnetic field is expanding; plenty of information is available for free at www.MagneticReversal.org – a site we made to be dedicated to the published research and key observations of ongoing magnetic changes and their effects on Earth.

3) Mechanisms and Miscellaneous Notes

In terms of week-to-week space weather, it will mostly be the larger events that cause technological disruptions; unfortunately, there is no way to tell where that will occur or if it will be widespread/everywhere in a major event. This is because there are multiple pathways for this energy to reach the ground:

a. SEP can penetrate into the atmosphere and GEC

b. CME compression of the magnetosphere pushes electrons into the atmosphere

c. Amplified auroral electrojets near the poles and equator can induce currents almost anywhere in the atmosphere and ground

d. All aspects of space weather events affect the ionosphere, and therefore the GEC

The systems most likely to go down are broadly based, heavily used- like communications services, GPS, gaming networks, airline internal systems, transformers and substations, and those that are poorly designed, like we see in many third world countries, and also in rapidly developing nations. In South America, Asia and Africa there are numerous high-risk grids that could leave the population in the dark. Interestingly, while major solar events produce notable effects, correlations are stronger during sunspot minima than during the quiet days of sunspot maximum due to the higher galactic cosmic rays present at that phase of the cycle.

In recent years, numerous countries are taking-on advanced geoelectric risk analyses from solar storms. Studies outside the United States, including numerous countries in Europe, and in New Zealand, and are finding their grids are also at considerable risk during major solar outbursts (Caraballo et al. 2019; Freeman et al. 2019; Rosenqvist and Hall. 2019; Tozzi et al. 2018; Divett et al. 2017). There are almost no electric grids on Earth properly prepared for a major solar storm.

More information on major solar outbursts can be found in Chapter 8.

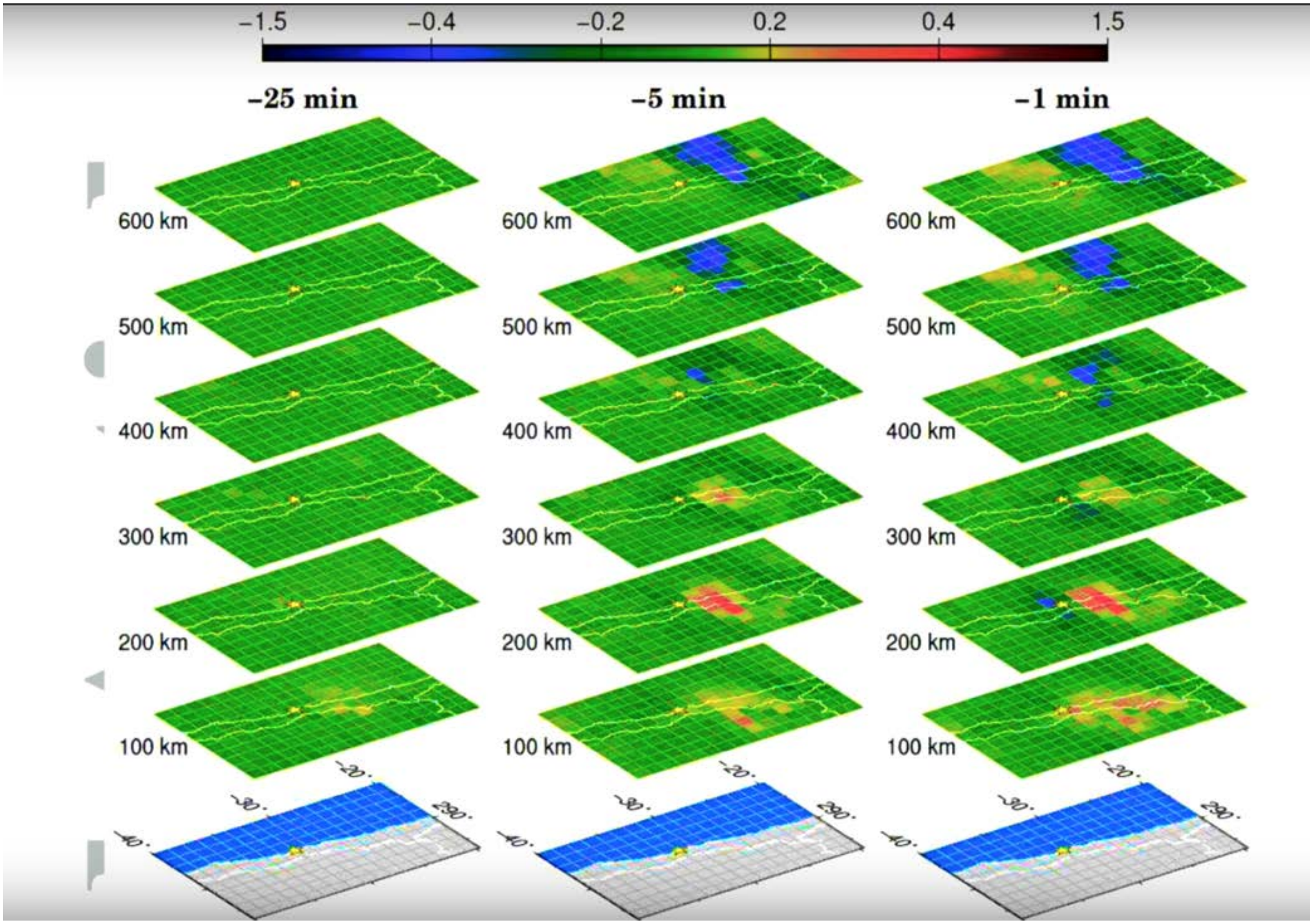
Key Points:

1) All technology is at risk from over-electrification.

2) Numerous major events involving air-traffic, power grids, spacecraft and digital systems have occurred in the technological age. Our modern grids could not handle some of the historic storms we know about from the pre-electrical age. The sun can return us to that period in a matter of hours.

3) The technological vulnerability appears to be increasing. This problem is a combination of (1) more-complex (and more at-risk) technology that is (2) overused/interconnected, and (3) Earth’s weakening magnetosphere- letting more energy into the Earth system.

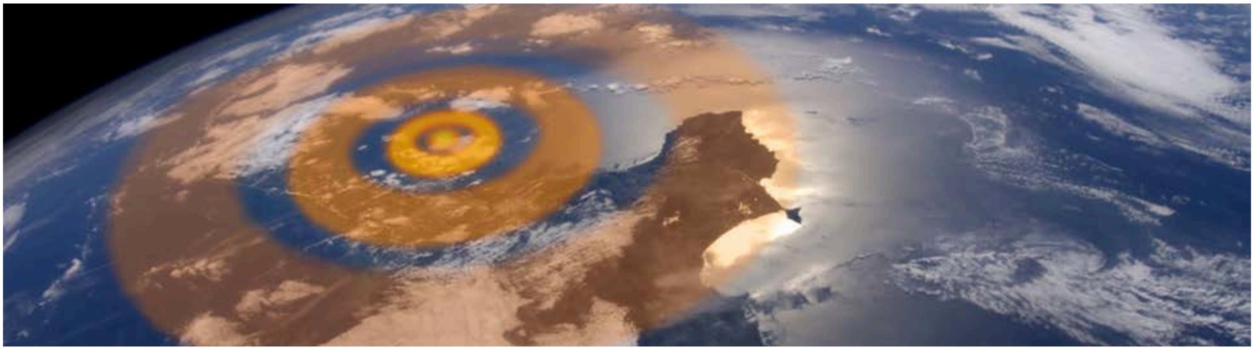
7.0 Solar-Triggered Earthquakes and Location Forecasting



He and Heki, Three-Dimensional Tomography of Ionospheric Anomalies Immediately Before the 2015 Illapel Earthquake, Central Chile, JGR, Space Physics 2018

This topic is one you really have to see to believe. Earthquakes are actively being forecast and the science here is moving faster than the space weather and climate/health fields combined. From ground tracking to satellite tracking to data analysis across the world- get ready to learn how to predict earthquakes.

The image above is from one of the most important papers in this field. It shows atmospheric electron content, with a surge in electrons from the upper atmosphere to the ground (blue deficit above, because they surged downward to the red patches). The timestamps above the columns are the number of minutes relative to the 2015 M8.3 earthquake in Chile. The surge began less than 30 minutes before the earthquake, became incredibly strong in the last 5 minutes, and was gone within a few minutes afterward. The little yellow stars in the images represents the epicenter, and the paper represented the first definitive tracking of a vertical GEC surge downward associated with an earthquake. Imagine a lightning bolt that lasts for 30 minutes, is dozens of miles across, is low density enough not to glow or be deadly at any one point within it, and its flowing directly up and down at a fault line. This is what happens before major earthquakes- an invisible tube of weak lightning, a plasma current.



7.1 Earthquake Timing: Using the Sun

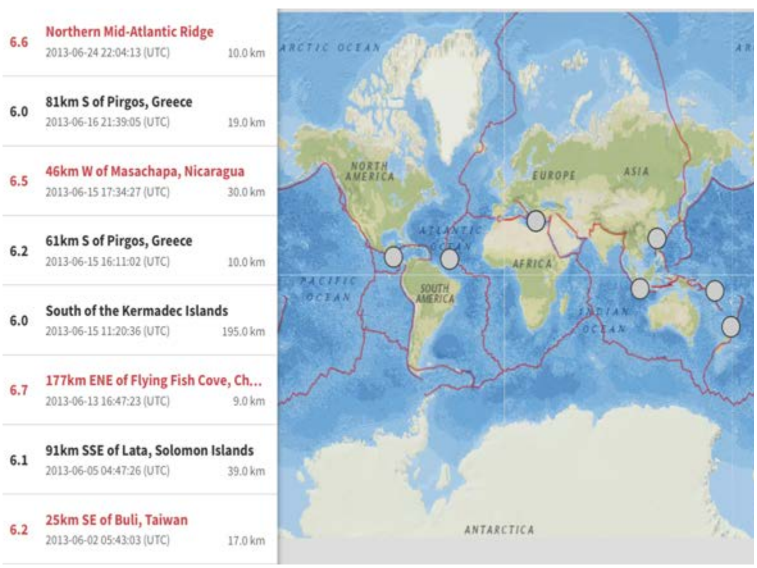
There are two aspects to forecasting a large Earthquake: Timing and Location.

The “timing” of an earthquake can be looked at from two basic perspectives: (1) “When will a big one strike Earth?” (2) “When will my location have a large earthquake?” If you are a forecaster in an earthquake zone, #2 is going to be vastly more important.

The factors that help determine the location of a large earthquake are always present and able to be analyzed, and those risk zones are constantly changing based on atmospheric signals and deep ground movement. Therefore, the “timing” of large earthquakes in this section will relate to #1- when the Earth is most at risk of having a large earthquake *somewhere*. #2 will refer to location-based forecasting.

Timing. Over long periods, the Earth has about three magnitude 6+ earthquakes per week, but when you actually track the data you often find many in a brief flurry of a few days and then go days to weeks without even one. The image below illustrates these fluctuations:

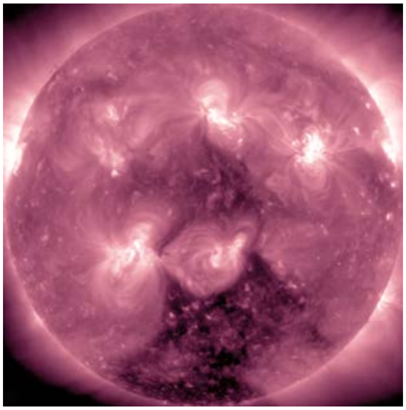
<u>This image lists all +M6 Earthquake in the first 4 weeks of June 2013 (Source: USGS)</u>



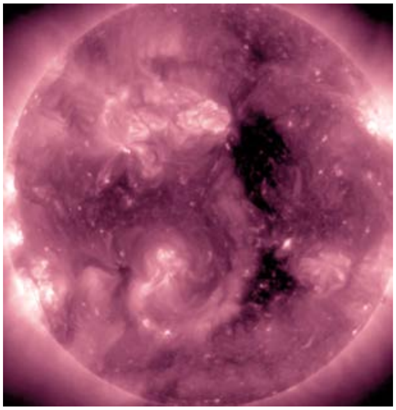
M6+ Earthquakes
Week 1: 2
Week 2: 1
Week 3: 4
Week 4: 1

The overall period had below average M6+ activity, with one week above average. This is typical, and over longer periods averages to three per week. The fluctuations, the peaks of activity where many more M6+ events occurred, are what we aimed to understand, and it has been very fruitful. As of 2018, just a few factors are able to foretell ~ 90% of these ups and downs in seismic activity at the M6+ level.

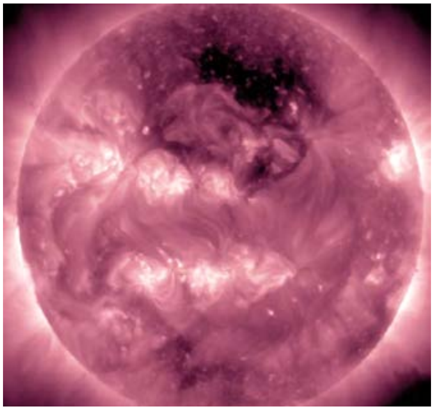
This timing analysis involves the use of coronal holes, which contain the direct IMF connections from the sun to the Earth (Section 1.1), and which affect the magnetism of the entire solar system. It also includes large solar eruptions that could add energy to that system more chaotically. The next images are just seven among the hundreds of examples of powerful coronal holes facing Earth during large earthquakes.



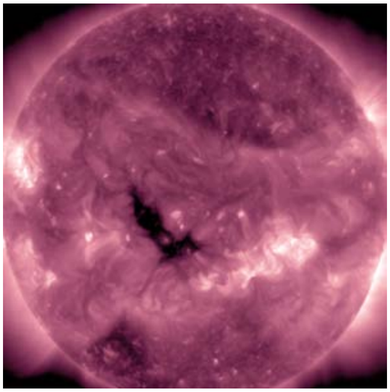
M9.0 in Japan - March 11, 2011



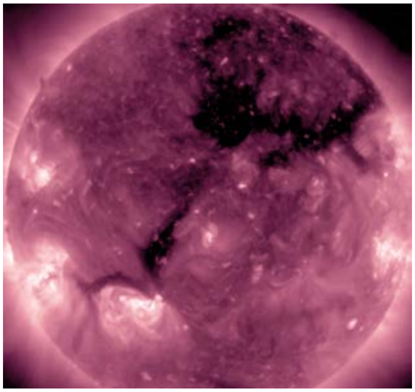
M8.6, 8.2 in Sumatra - April 11, 2012



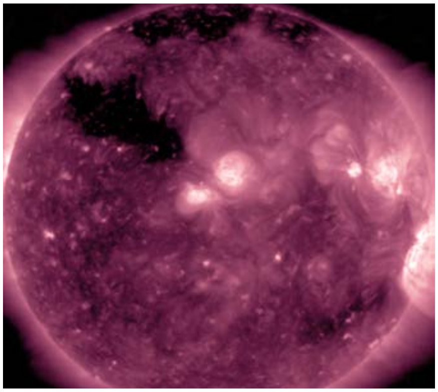
M8.3 in Russia - May 24, 2013



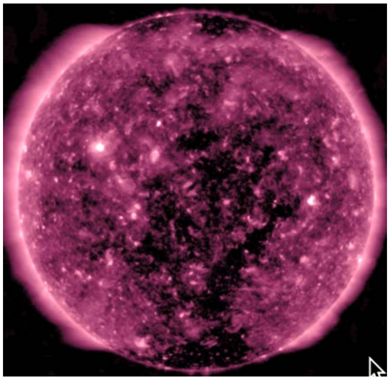
M7.9 in Alaska - June 23, 2014



M8.3 in Chile - September 16, 2015



M8.2 in Mexico - September 8, 2017



M8 in Peru – May 26, 2019

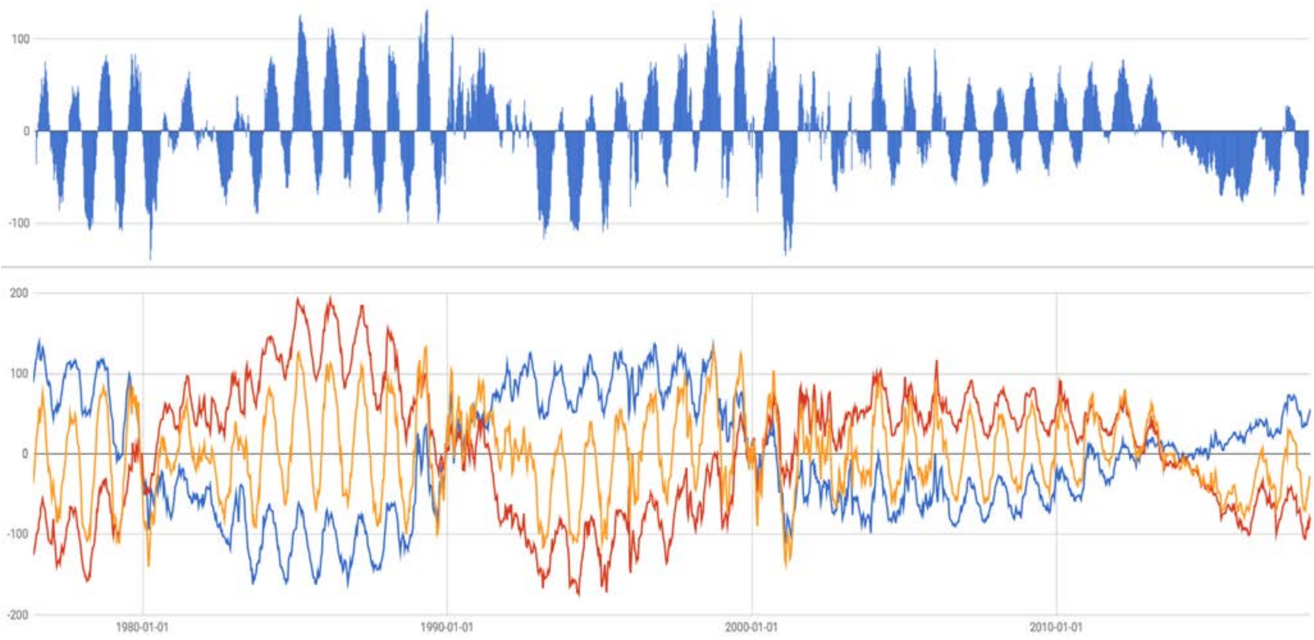
Daily Sun/Earth reports available at SpaceWeatherNews.com always cover coronal holes and earthquake connections.

When it became clear that a way to quantify this relationship was needed, we found that little information existed apart from data on the IMF from polar coronal holes, known as the solar polar fields (SPF). While not as good as equatorial field data, the SPF would serve as an analogue to the power of the coronal hole facing Earth.

With the available data (1976 to present) we worked with Dr. Holloman (Professor of Statistics, The Ohio State University) and Dr. Kongpop U-yen (Goddard Space Flight Center, NASA) to find a correlation with the largest earthquakes.

Paper: Davidson, B., U-yen, K., Holloman, C. (2015) Relationship Between M8+ Earthquake Occurrences and the Solar Polar Magnetic Fields. *New Concepts in Global Tectonics Journal*, V.3, No. 3, September 2015, pp. 311-323

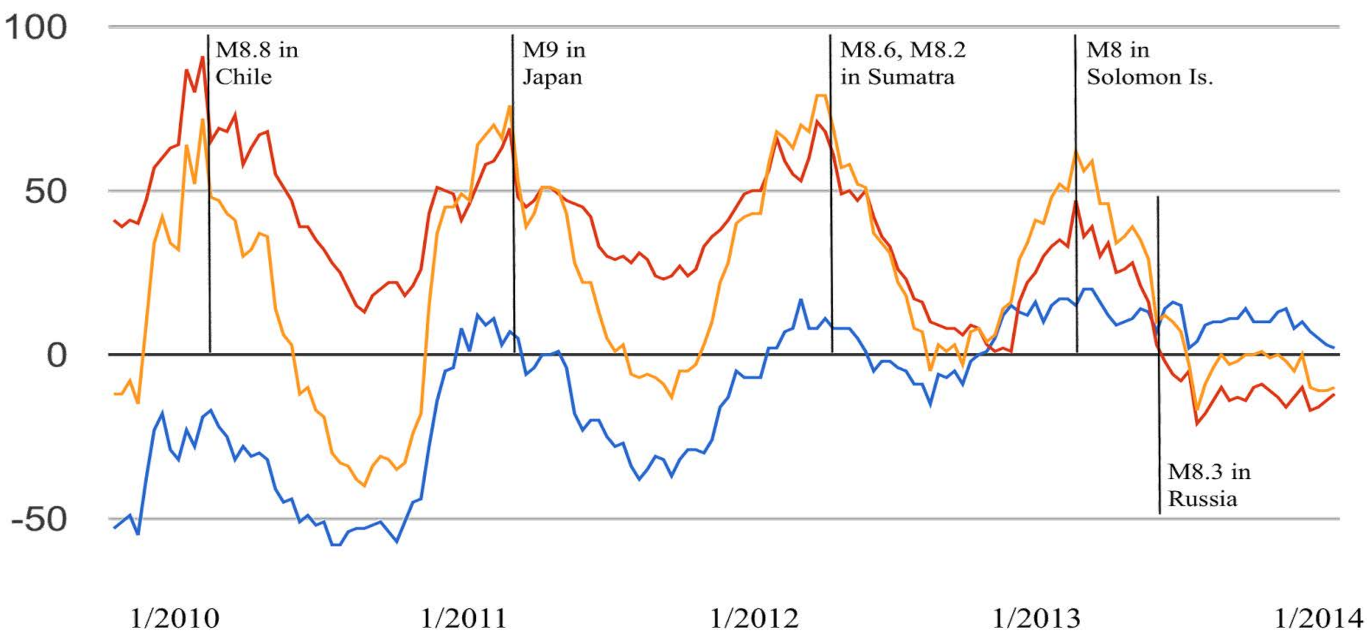
To our surprise, it was the largest earthquakes (M8+) that showed the strongest relationship with the sun, demonstrating a result that was nearly impossible to find by random chance, and showing that the larger the earthquake, the more help it might need from the sun or the GEC or both. The biggest earthquakes occurred close in time to the magnetic peaks and reversals of the solar polar fields. Below we see the data on the solar polar fields from 1976 to mid-2018:



The figures above are (top) the SPF magnetism to which Earth is subject in total, and (bottom) the north (blue), south (red), and total fields (yellow, N+S). The data comes from the Wilcox Solar Observatory at Stanford. The vertical axis is + or - magnetism in microTesla. The “up and down” you see on top, and in each of the curves below, have an approximately 1-year frequency.

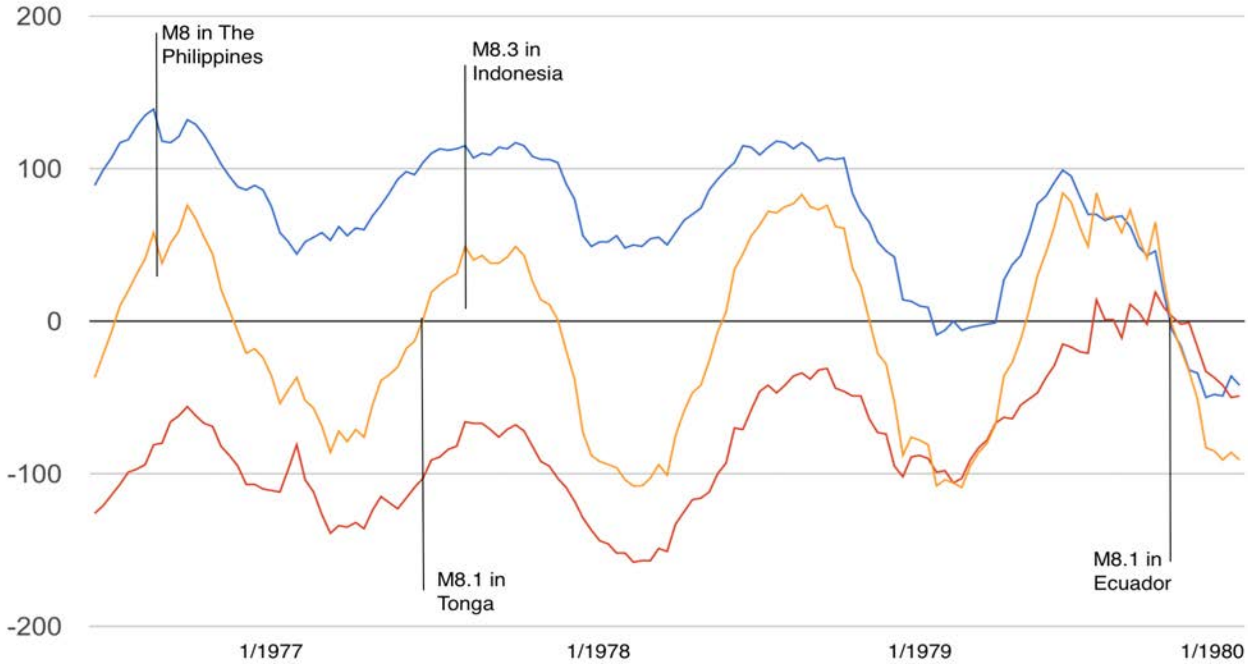
The 11-year solar cycle is evident in both charts but more easily seen on the bottom, where the north and south form nice bubbles ~11 years long and culminate with a reversal of the north and south curves across the 0 line, changing polarity. Sunspot maximum comes with a polarity reversal of the SPF, and so the strongest periods of SPF magnetism occur during sunspot minimum. The shorter, 1-year fluctuation is due to Earth’s slight orbital tilt, which goes from 7 degrees below to 7 degrees above the solar equator, making Earth more exposed to either the south or north SPF at that time, causing the 1-year fluctuation.

The relevant moments in a variable electromagnetic system are the peaks in magnetism and the reversals of polarity (+/-); that is, the strongest magnetic moments, and when the push becomes a pull, or a pull becomes a push. Below are some images from our papers and subsequent research.



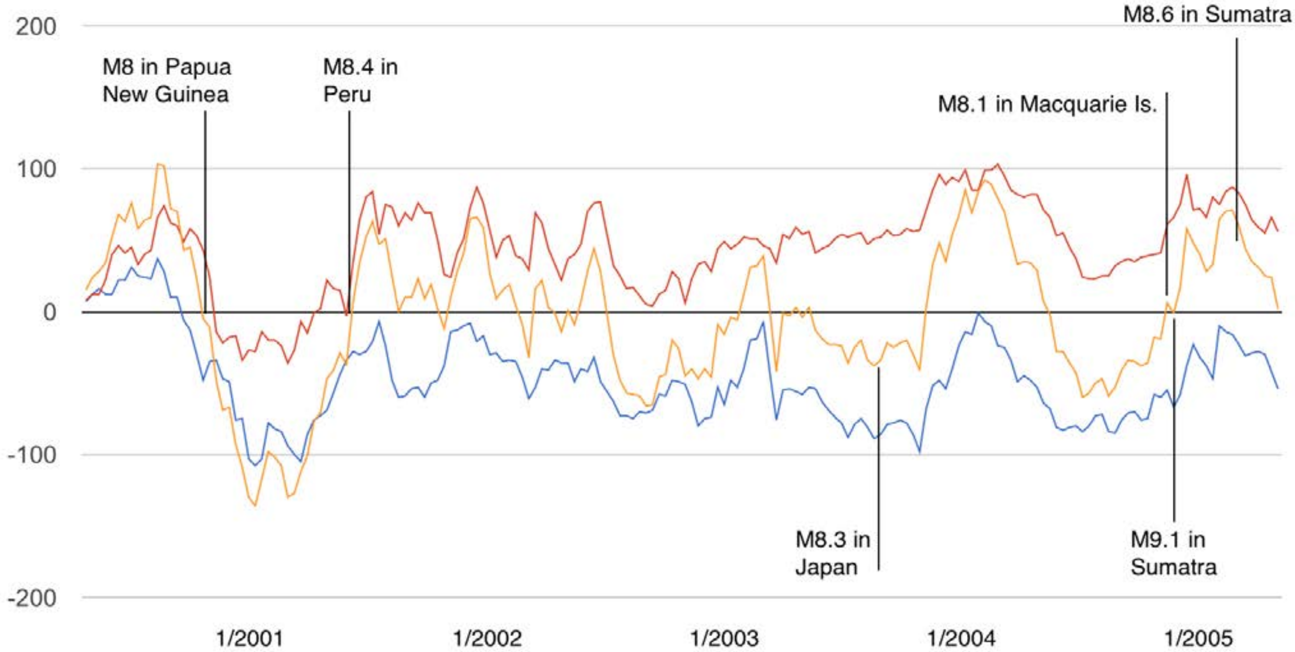
This first graphic is straight from the paper: these were the last six M8+ earthquakes as of the time analysis began in January 2014; note the two events striking on the same day in Sumatra in 2012. The first four M8+ earthquake days occurred less than one week from the positive peak in strength in the 1-year oscillation of the southern (red) and total (yellow) SPF; the Japan and Solomon Islands events occurred within 48 hours. The final M8+ event to occur before the analysis began occurred on the day those southern SPF (red) reversed polarity.

This is actually what started the entire investigation: seeking out solar cycles, finding the SPF cycle, and noticing a pattern to the dates of these peaks. After going through the entire M8+ earthquake record back to 1976 (when the SPF data begins) we sought the help of a mathematician/statistician, along with an expert in the physics realm of the topic. With the help of Dr. Holloman and Dr. U-Yen, the analysis kick-started the paper, an App, a satellite, and even more science.



We began with the most recent earthquakes as of the analysis period; let’s go now to the beginning. The image above shows the first four M8+ earthquakes of the SPF-data era that began in 1976. It also demonstrates the fluctuations in M8+ activity, since we can have 2-3 in a year (or go years without one), and we see that irregularity here- which was largely absent in the first image.

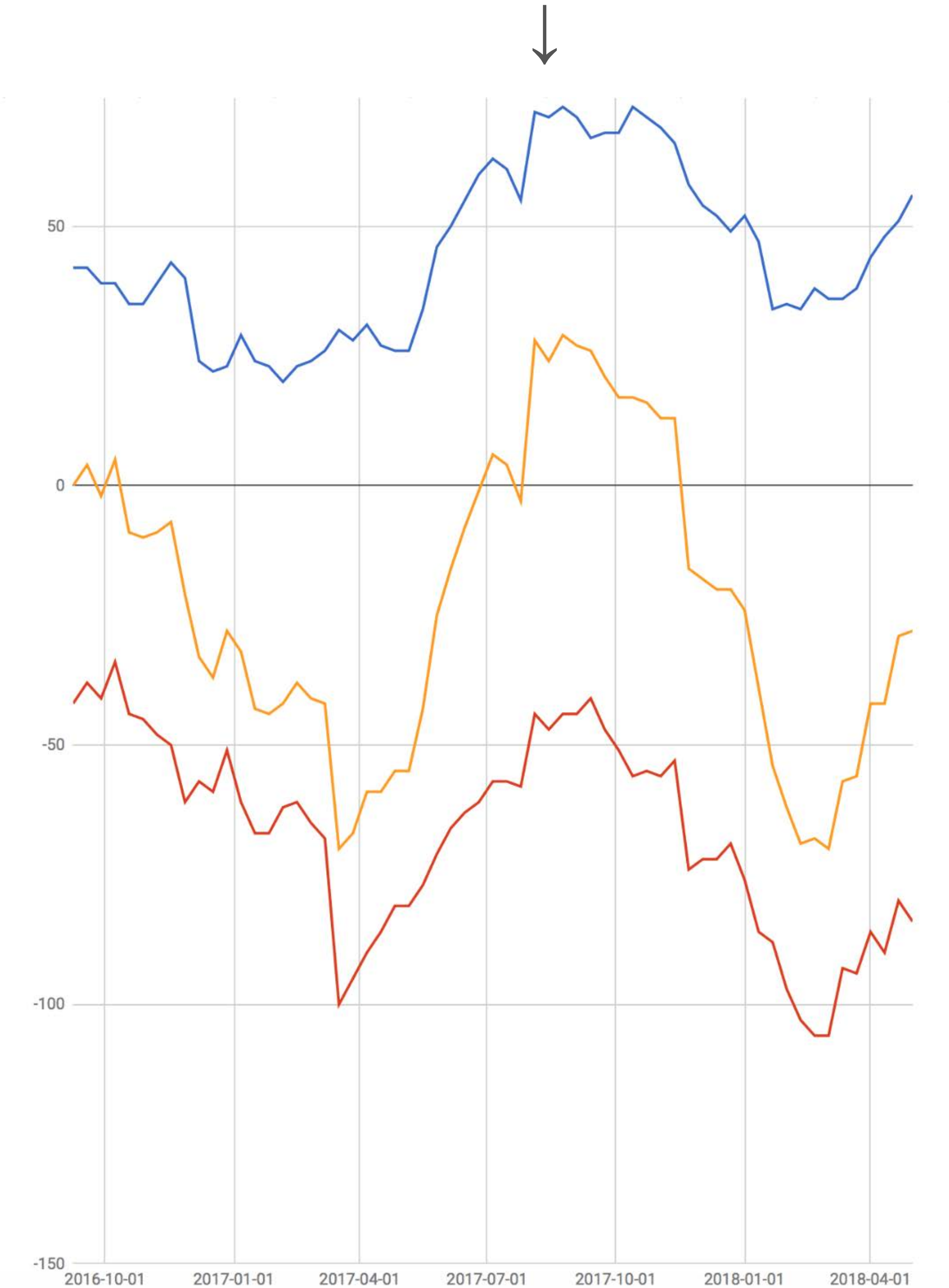
When we focus on the four largest earthquakes of this 3.5 year period, we find that they hit, in sequential order, (1) a peak in northern SPF (blue) positive magnetism, (2) a reversal in the total SPF magnetism (yellow) where the sun’s total force on Earth went from - to +, (3) another peak of the northern SPF magnetism, and (4) a triple reversal period (all three curves reversing).



In this image we see a stretch from 2000 to 2005 in which six M8+ earthquakes occurred, again showing the irregular nature of the occurrence of these massive events. The first two events on the left struck total SPF (yellow) reversals.

The next one, the M8.3 in Japan, was one of the few M8+ events that did not match the model. It is notable that there appears to be small negative polarity peak in northern SPF (blue) at that time, but our model required a larger peak to count. Could that in-fact be a part of this causation pattern? Could we have made a mistake in the threshold? Sure, but it did not make the cut-off in the model we created, and that’s how science works. Can you *guess* that it was probably a hit outside our human-made model? Yes, probably, and it was the sun.

The last three quakes on the right included the Christmas tsunami disaster in Sumatra. During this time the total SPF (yellow) stumbled through a double reversal itself, with both coinciding with large earthquakes, followed by the final one during the final positive peak of the southern SPF (red) in 2005.



This graphic contains the SPF curves for late 2016 through mid-2018. Only one M8+ earthquake occurred, an M8.2 in Mexico on September 8, 2017. The black arrow at the top of the image shows that date, amidst a peak in northern SPF (blue) positive magnetism.

Whether tracking the weekly fluctuations of M6+ earthquakes or the conditions surrounding the rare M8+ earthquakes, more-specific timing may be tied to coronal holes. The IMF connecting Earth and sun always comes from those coronal holes, and the SPF is merely the high latitude IMF, which can simultaneously inform us about both the IMF strength of lower latitude regions and the power of the sun's magnetic poles themselves.

Important notes on the field:

- While only a few papers existed on the topic of the sun and earthquakes a few years ago, there were certainly previous suggestions of a correlation (Midya and Gole 2014; Tavares and Azevedo 2011, Odintsov et al. 2006).

- The field has since become dominated by successful searches for a relationship between the sun and large earthquakes, virtually erasing all doubt as to the topic of a correlation, and extending to space weather phenomena such as solar flares, SEP events, CMEs, geomagnetic storms, and IMF polarity in the solar wind- the polarity reversals embedded in the solar wind itself (Phi angle, Bz - Chapter 1). (Marchetti et al. 2020; Venegas-Aravena et al. 2019; Das et al. 2018; Marchetti and Akhoondzadeh 2018; Velichkova and Kilafarska 2018; Casati et al. 2017; Cataldi et al. 2017; Elfaki and Yousef 2017; Hagen and Azevedo 2017; Yu et al. 2017; Straser et al. 2017; Sukma and Abidin 2017; Larocca 2016; Midya et al. 2016).

- Our paper with Dr. Holloman and Dr. U-yen has been cited eight times as of January 2020.

- **A few NASA scientists have also begun tracking a significant correlation between geomagnetic activity and large earthquakes (Urata et al. 2018)**, which logically *should* exist based on the fact that SPF and geomagnetism follow the same 11-year cycle and have two peaks per year. Subsequent studies have confirmed the merit of a geomagnetic forcing investigation (Marchetti et al. 2020).

- The IMF (SPF included) does not contend with the magnetosphere- it couples, connects, and its plasma delivery directly bypasses Earth's primary defenses.

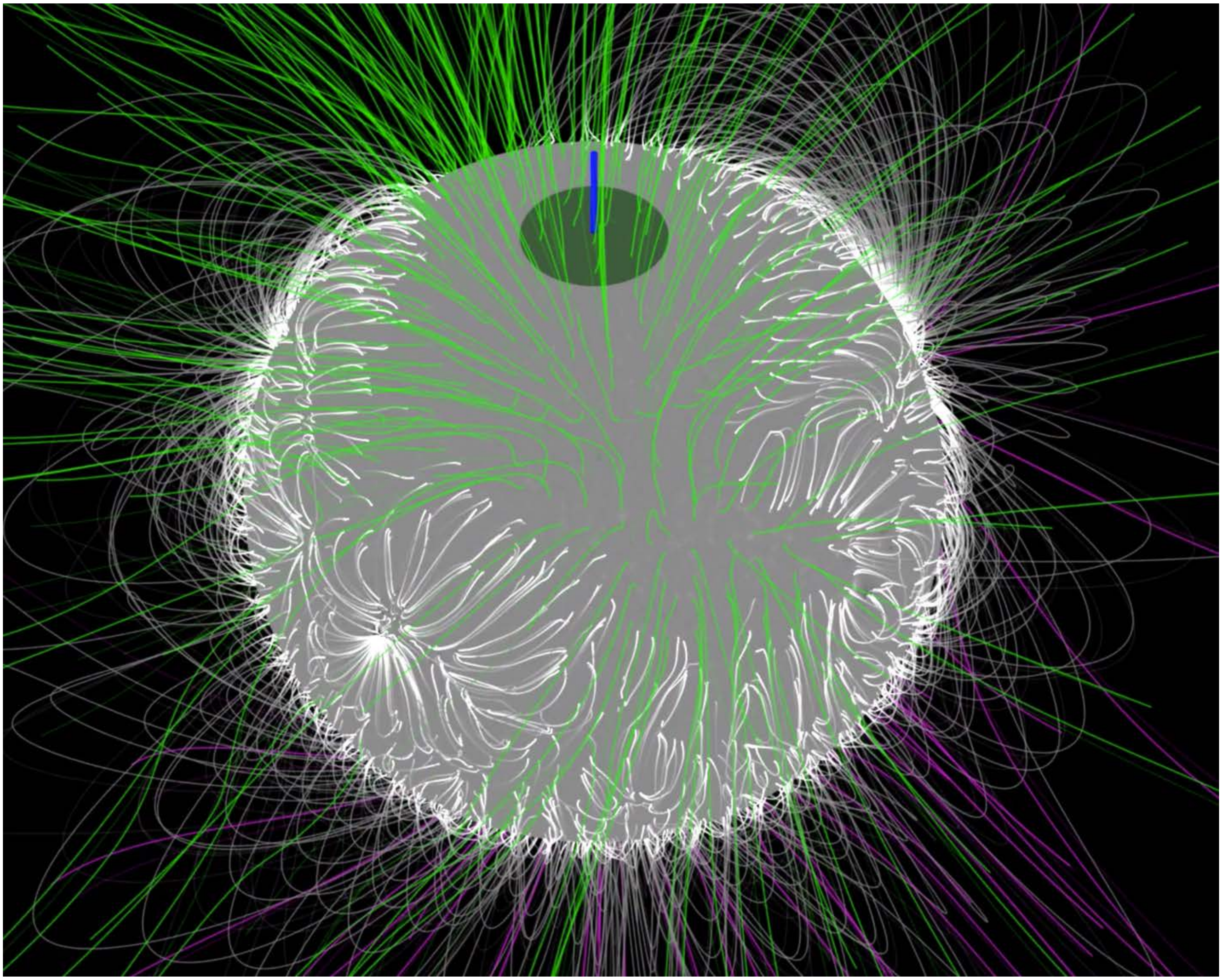
Key Points:

1) The sun can inform us about long-term cycles and patterns in seismic data, as well as indicate imminent times of large-magnitude (M6+, M8+) risk.

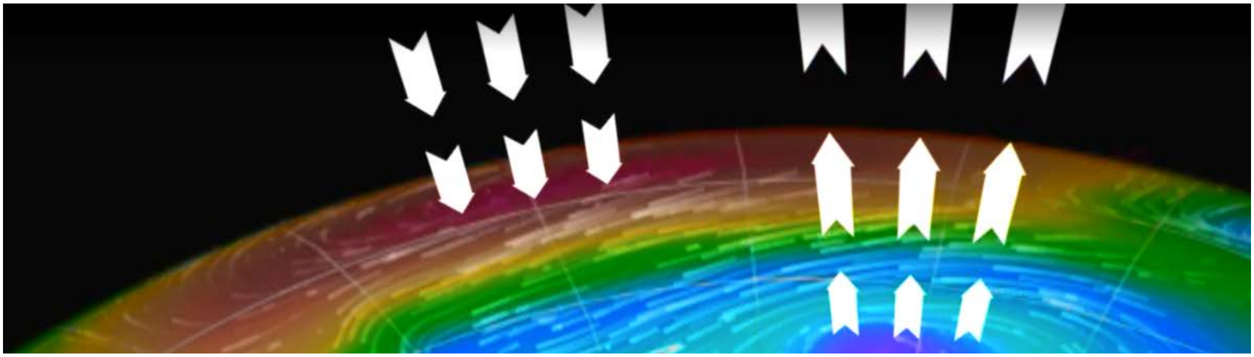
2) The solar polar fields (SPF) correlate well with the M8+ earthquakes, which occur most-often when magnetism of the sun is peaking or reversing polarity.

3) Coronal hole IMF modulates the cycles of activity of M6+ earthquakes.

4) Other correlations between the sun and earthquakes have been made on long (11-year cycle) and short (hours/days/weeks) time periods using solar flares, CMEs, geomagnetic storms, and IMF polarity in the solar wind.



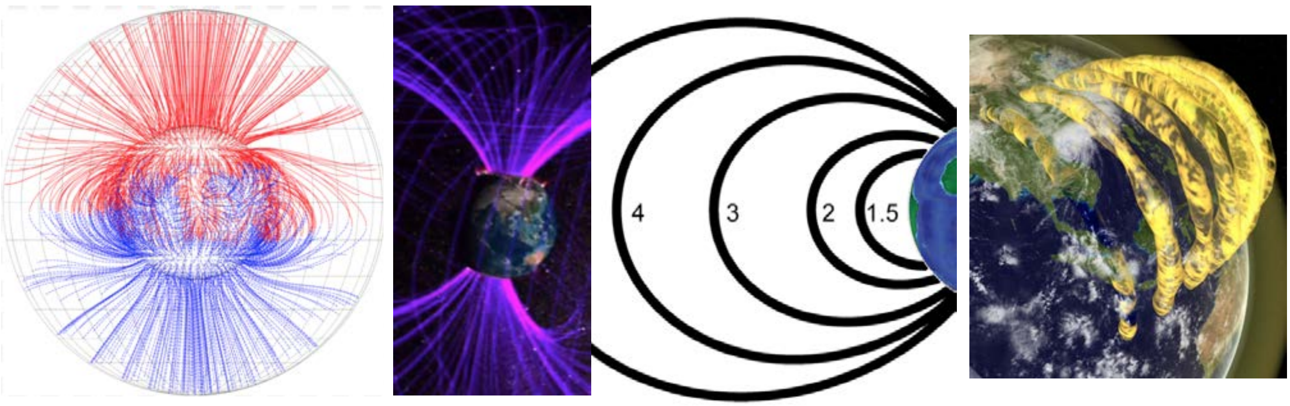
Magnetic Fields of the sun, focused on the N pole. NASA/Goddard Scientific Visualization Studio



7.2 Earthspots

Earthspots: Places where the global electric current (GEC) manifests as weather and other Earthly phenomena as they travel up or down through the atmosphere and the ground. Under high pressure and clear skies, the electric currents come down from the ionosphere, currents flow back upward in storms and low pressure. This is what we covered in Chapter 5; those pressure cells are the Earthspots.

Why not just call them pressure cells? High and low? That answer lies in the structural and electromagnetic similarities between Earthspots and sunspots. Let's begin our examination with the magnetic fields of the Earth and sun spheres.

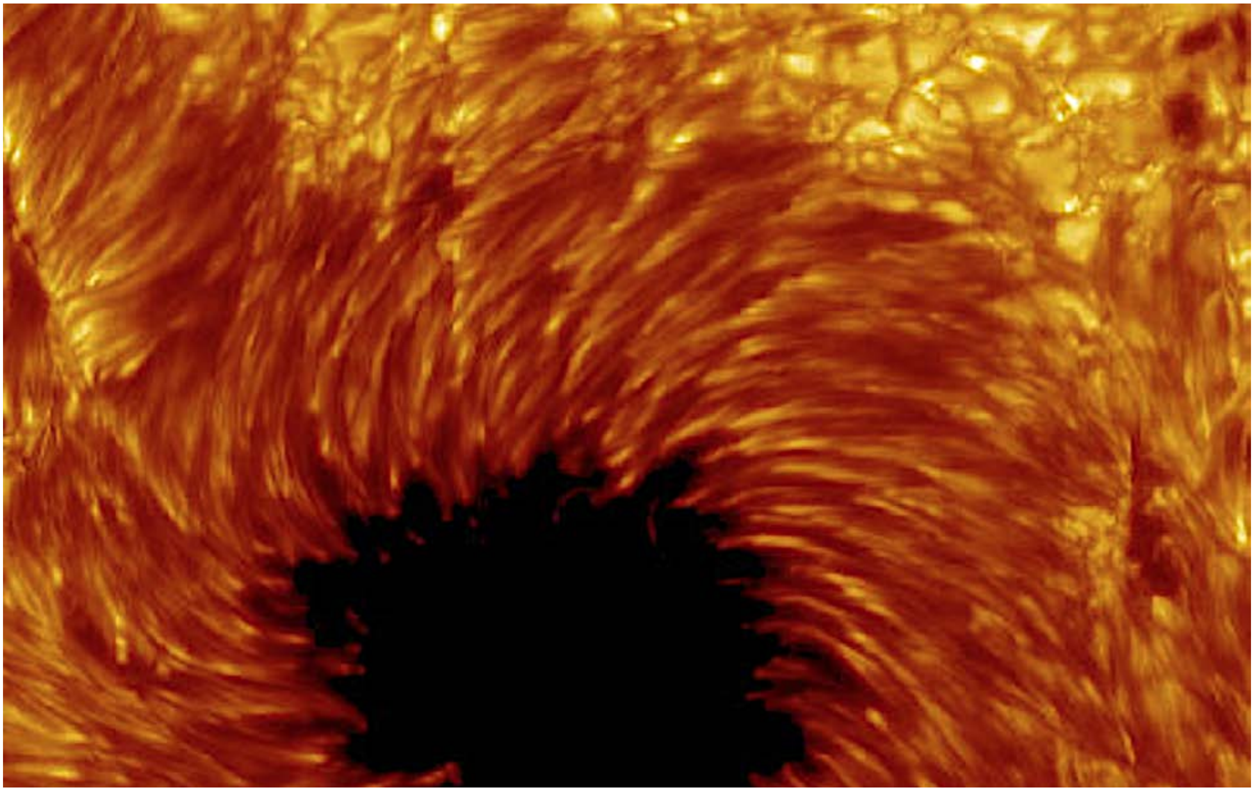


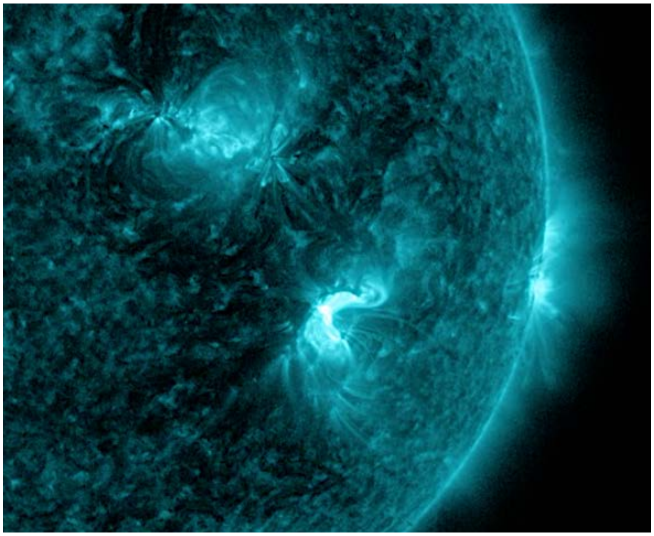
Sun **Earth** **Earth** **Earth**

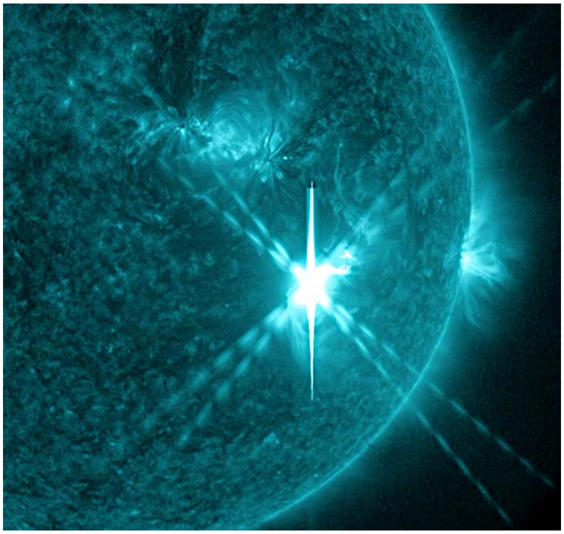
From left to right: 1) the Sun's north/south 'dipole' magnetic field, and the coronal magnetic fields arching above the solar equator, 2) Earth's 'dipole' component of the magnetosphere (north/south), 3) Earth's "L shell" magnetic fields, and 4) the plasma tubes tracing the lower levels of the shells over the magnetic equator.

Earth and sun have similar global magnetic field structures. On the sun, these are well-known to drive the sunspot cycle. On Earth, scientists are JUST NOW learning how the magnetic fields/GEC affect storms and weather. Speaking of storms, let's move on to the similarities of the storms on the Earth and sun.

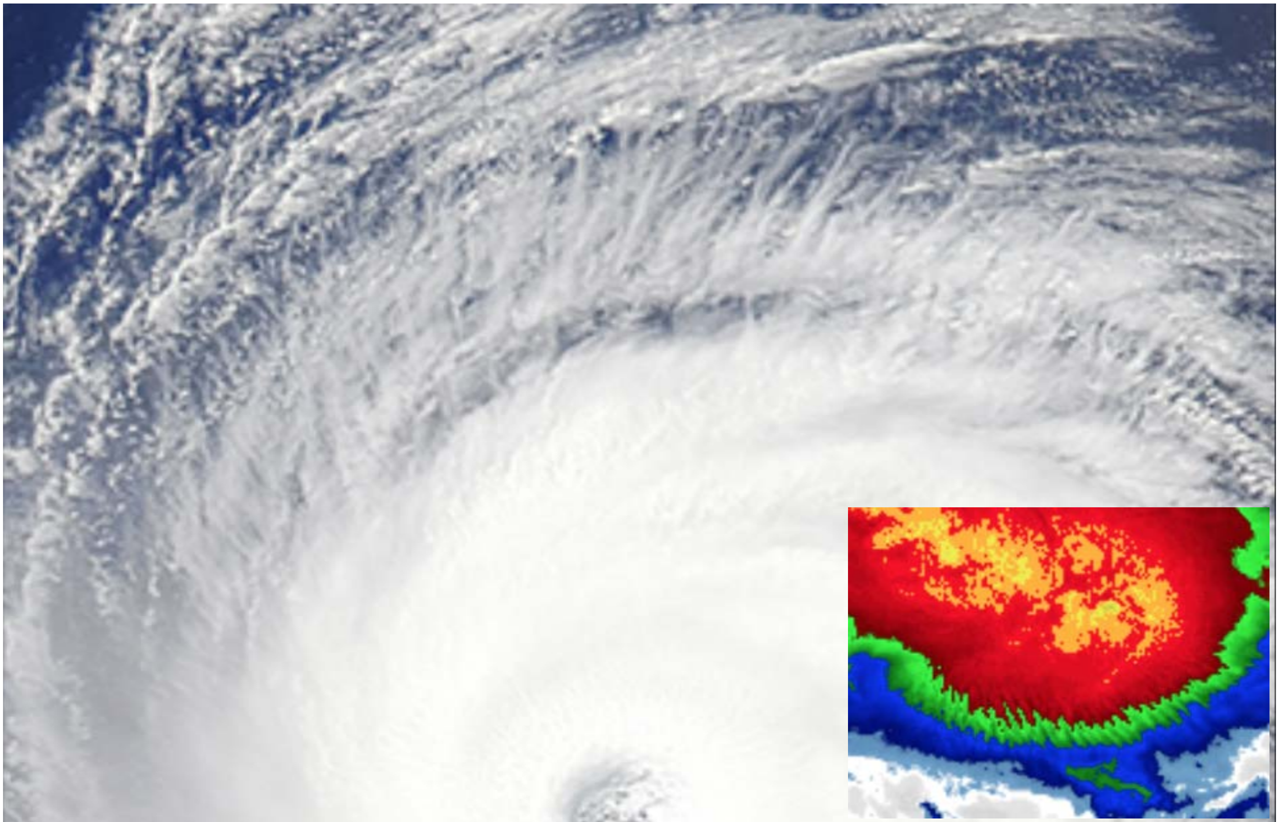
On this page and the next one, red, blue and purple text are meant to be tied to one another.

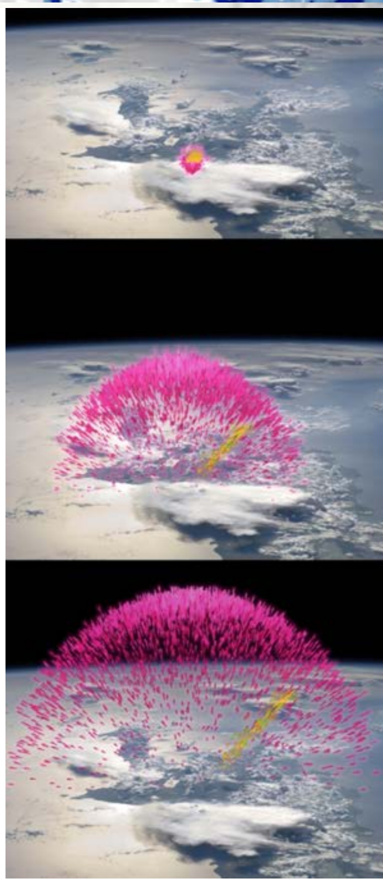






Sunspot structure consists of a dark central “umbra”, surrounded by penumbral strings that spiral out from the center. Sunspots are constantly flashing with low level nano-flares, which look like lightning in and around the sunspot, and in a big solar flare, there is a huge surge of electromagnetic energy released into space.



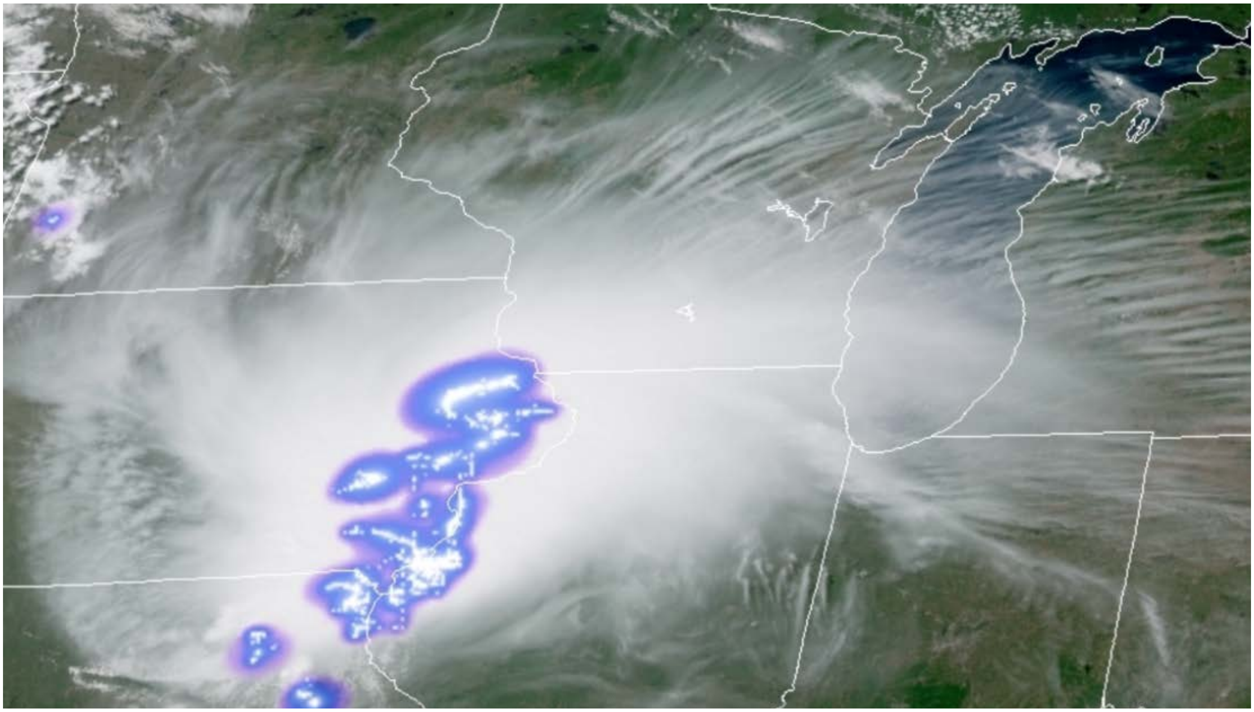


While not every hurricane or typhoon looks as perfectly like a sunspot as this one does, there is almost no such tropical disturbance that does not present the “penumbral strings”- those lines you can see striking through the clouds and vapor return. While these Earthly cloud features are called whistlers, it would be a mistake not to notice how they all spiral out from the eye of the hurricane, like the penumbral lines do in sunspots.

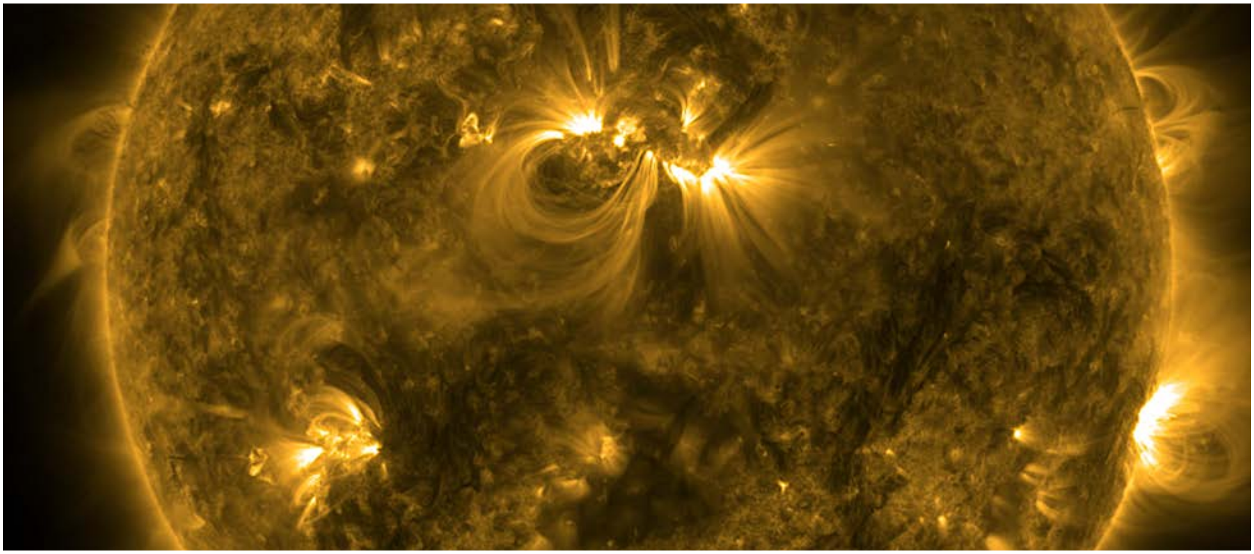
The storms on Earth are constantly flashing with lightning strikes, and when storms have a truly energetic lightning burst, they release a “terrestrial gamma flash” and shoot high-energy electromagnetic waves up into space (images right).

Not only do Earth and sun have similar global magnetic structures, but the storms are structurally similar and behave similarly in an electromagnetic manner.

On the next page is another image of the “penumbral strings”, visible in a thunderstorm over the United States, via GOES-16, as an example.

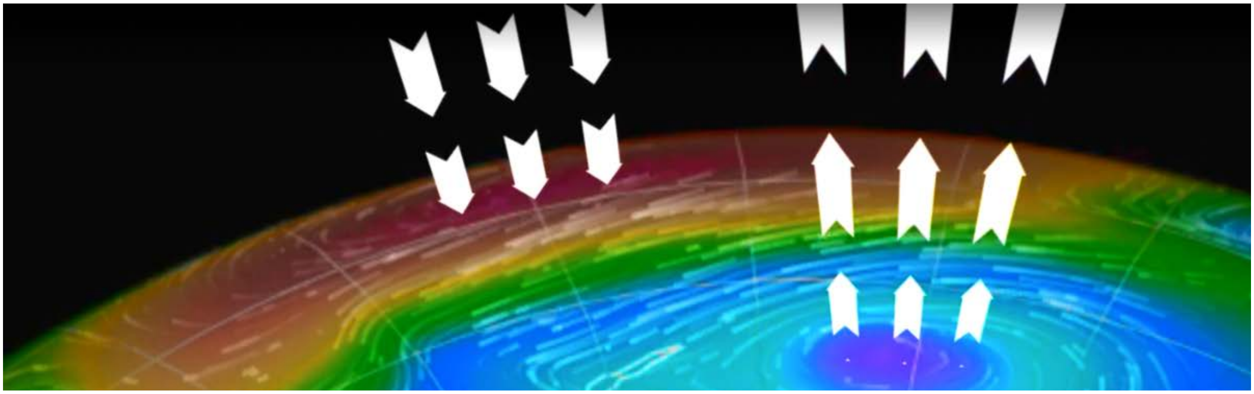


Time for the icing on the cake:



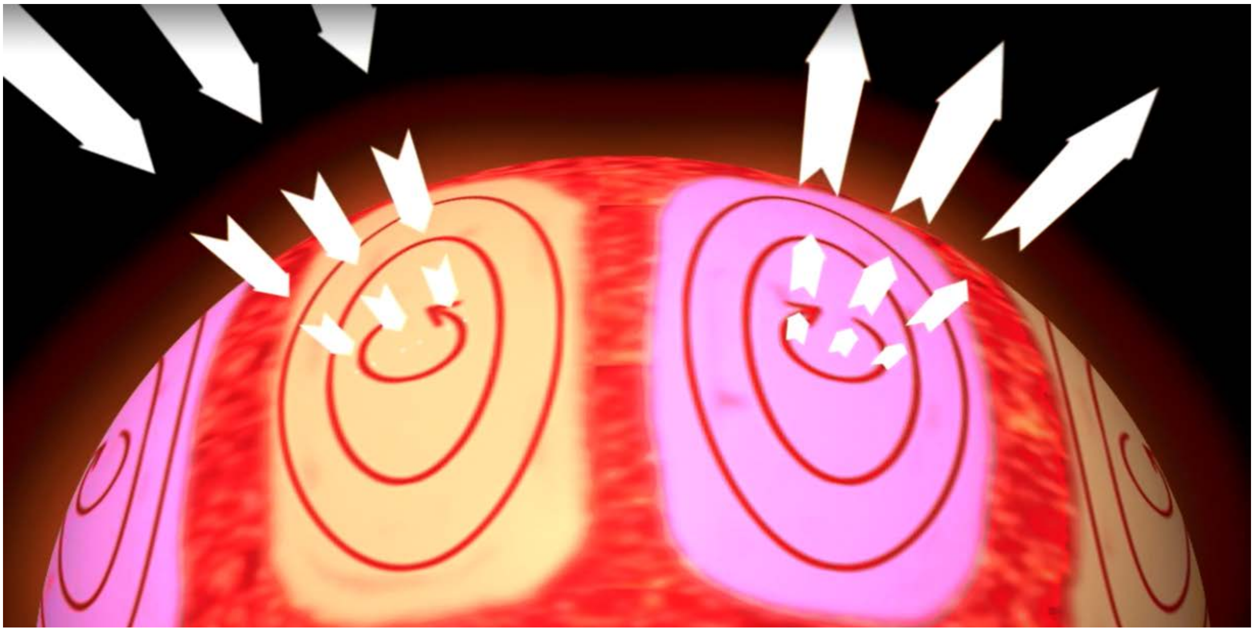
In the solar image above, the umbral magnetic field loops (arches) you see give away the key electromagnetic similarity between Earth and sun. These fields connect sunspot to sunspot, and only at opposite polarity sunspots. Similarly, in the GEC, we only see particles coming upward in low pressure, and heading to the ground in high pressure.

Just like positive and negative sunspots connect up and down flows of charge and plasma, Earthspots do the same on Earth.



For meteorologists, and those who know about Earthly Rossby waves, similar waves were discovered on the sun as well, driving many of the large-scale patterns we see in sunspots and coronal hole locations. Some of the more-fluctuating solar Rossby wave events look astonishingly similar to the “Omega block” of the jet stream we see on Earth.

These waves are related to large counter-rotating cells on the sun, like Hadley cells on Earth. Just like the alternating spin of the high and low Earthspots can inform us where the GEC goes up or down, on the sun they tell us where the IMF is coming in vs going out (image below). While the sun rotates left to right from our perspective, these cells travel right to left relative to higher latitudes on the sun, just like tropical storms do near the equator on Earth.



SpaceWeatherNews image by Xaviar Thunders, tilted to show white current-arrows. Equator of the sun runs through cell centers.

On the Earth, we find the strongest land-based storms like derechos, hail, lightning and tornado activity within “squall lines” or “convergence lines” between the GEC Earthspots where the wind flow is enhanced as air masses crash together. On the sun, the solar flare is most-likely to occur between/above the region between delta class sunspots.

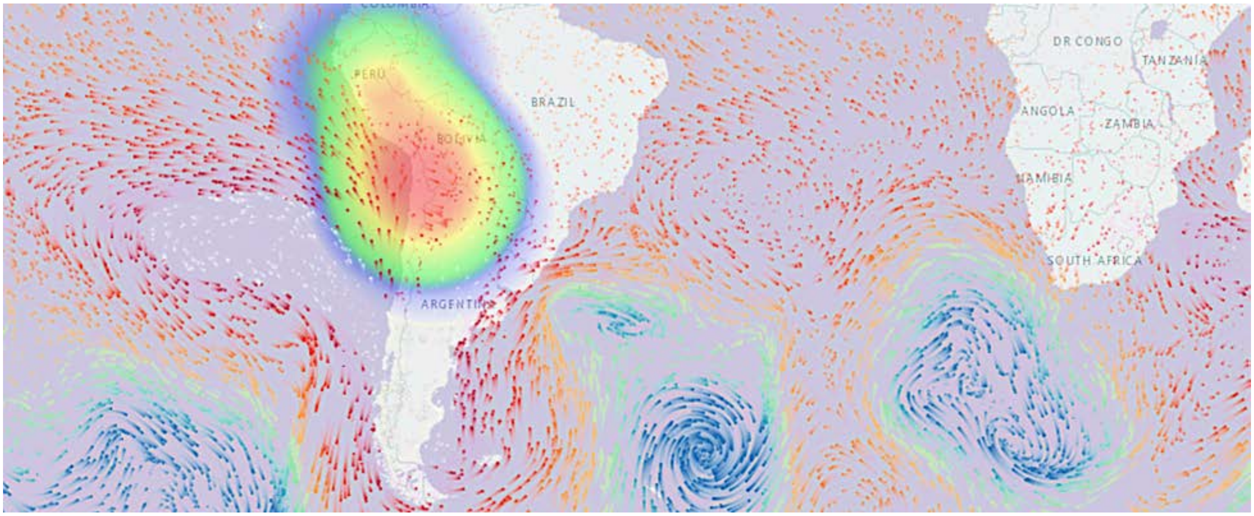
Key Points:

1) Global magnetic fields, storm systems, current flows and large atmospheric structures are similar on the Earth and sun.

2) Strong Earthspot lows (like hurricanes) demonstrate a remarkably similar structure in the visible clouds to what we see in sunspots.

3) The small and large-scale electromagnetic emissions of the storm systems are similar in pattern and energy range on both Earth and sun.

4) When sunspots get active, similar storms get active on a planet electromagnetically connected to the sun (Chapter 5). This is more than temporal coincidence, it is electromagnetically crying out to be noticed.



7.3 Earthquake Location Forecasting: Using GEC "Earthspots"

Some of the energy coming down in the GEC (high pressure) goes into the ground where it can trigger an earthquake or a volcano eruption immediately, or it can build up charge and then release later as an earthquake or volcano eruption. **If a thunderstorm is a GEC electric storm in the atmosphere, there is certainly a GEC electric storm component to earthquakes.** The science behind this claim and its proof by application follow in this section.

The electrical signals of the global electric circuit are used to determine when/where this energy might interact with a fault zone.

In the middle and early part of the last decade, there was a developing precedent for this pursuit in published work looking at pressure, storms, electrical changes in the atmosphere, and thermal radiation escape before large earthquakes (Lu et al. 2016; Oyama et al. 2016; Kong et al. 2015; Chen et al. 2010; Jing et al. 2010).

However, whereas each study was focusing retroactively on one signal, like GPS disruptions or electron content changes in the atmosphere, analyzed after an earthquake had already occurred, we sought to combine the total body of work to proactively predict the location of large earthquakes.

In the time since our real-world forecasting began there has been confident scientific evidence that the fault structure and activity play a significant role in the GEC, lightning and Earth's pulse-electromagnetic field structure (Kappler et al. 2019; Argunov 2017; Malyshkov et al. 2017; Parrot 2017; Straser 2016) and that an electromagnetic pre-earthquake process helps release excess Radon and other ionized gases from the ground prior to large events (Tareen et al. 2019; Zoran et al. 2019; Karastathis et al. 2017).

Here are some notes to help understand the current state of the field. The electromagnetic pre-earthquake process shows itself in various ways:

1) A number of studies confirm outgoing longwave radiation (OLR) anomalies (including those tied directly to land surface temperature anomalies and surface latent heat flux) in relation to pre-seismic processes at the eventual epicenter. It is notable that land surface temperature/OLR anomalies require an extended period of high pressure and sunlight, which is the opposite (GEC) Earthspot from the powerful storms, and which causes a build-up of charge.

(Hazra et al. 2020; Akhoondzadeh et al. 2019; Jing et al. 2019; Lin et al. 2019; Pavlidou et al. 2019; Zoran et al. 2019; Akhoondzadeh et al. 2018; Barkat et al. 2018; Chakraborty et al. 2018; Huang et al. 2018; Mahmood et al. 2018; Ouzounov et al. 2018; Velichkova and Kilifarska 2018; Zhang et al. 2018; Bellaoui et al. 2017; Bhardwaj et al. 2017; Freund et al. 2017; Jiao et al. 2017; Joshi et al. 2017; Mahmood et al. 2017; Venkatanathan et al. 2017; Xiong and Shen 2017; Yan et al. 2017; Zhou et al. 2017; Zoran et al. 2017).

2) GEC and ionospheric/magnetosphere pre-earthquake anomalies have been confirmed, including those involving ionospheric critical frequency, total electron content (TEC), GPS disruptions, atmospheric ionization “earthquake lights” and various electromagnetic phenomena from the ground to the top of the atmosphere.

(Sekertekin et al. 2020; Shah et al. 2020; Sharma et al. 2020; Marchetti et al. 2020; Ahmad et al. 2019; Akhoondzadeh et al. 2019; De Santis et al. 2019; Lin et al. 2019; Sotomayor-Beltran 2019; Zhu et al. 2019 [1]; Devi et al. 2018; Karaboga et al. 2018; Namgaladze et al. 2018; Ouzounov et al. 2018; Perrone et al. 2018; Enomoto et al. 2017; Freund et al. 2017; Iwata and Umeno 2017; Jansky and Pasko 2017; Kelley et al. 2017; Kim et al. 2017; Krankowski et al. 2017; Ouzounov et al. 2017; Parrot 2017; Sharma et al. 2017; Sheshpari 2017; Xu et al. 2017).

3) Magnetic pulses/anomalies in the VHF/ULF/VLF/ELF ranges have been found to appear before large earthquakes at or above the epicenters.

(Sharma et al. 2020; Straser et al. 2019; Venegas-Aravena et al. 2019; Phanikumar et al. 2018; Potirakis et al. 2018; Takla et al. 2018; Cataldi et al. 2017; De Santis et al. 2017; Heraud et al. 2017; Naidu et al. 2017; Shen et al. 2017).

4) The most powerful Earthspots (hurricanes, typhoons, cyclones, tropical & extratropical storms) have been associated with electromagnetic processes before large earthquakes.

(Parrot 2017; Lin 2013; Liu et al. 2009).

5) Recently, abnormal gravity waves in the stratosphere have been detected prior to large earthquakes. Other atmospheric parameters like pressure, wind speed and temperature are also seen to fluctuate before seismic events in the same way as electromagnetic forcing from solar activity.

(Hazra et al. 2020; Yang et al. 2019 [2]).

As of 2020 the standard textbook on Electroquakes is published by the AGU, pictured left. In February of 2018, China and Italy launched the Seismo-Electromagnetic Satellite to detect the types of electromagnetic anomalies described in the literature.

Many of the 2019 and 2020 studies on electromagnetic anomalies preceding earthquakes listed in this section used data from this satellite.

Website for the China/Italy Satellite to detect electromagnetic pre-earthquake anomalies from the day after launch. http://cses.roma2.infn.it

It was our goal to combine the various factors and engage a real-world forecasting model from the total volume of published work. The studies were easy to find, but difficult to track, and most data (critical frequency, TEC, GPS data, and similar ionospheric data points) is not available in real-time, or at least in any processed form that would be useful. Even in the exceptions, most are not able to deliver localized information, and there are various terrestrial phenomena that can produce similar signals (like cyclones, volcanoes, geomagnetic storms) to those before earthquakes- which leads to many false positive alerts.

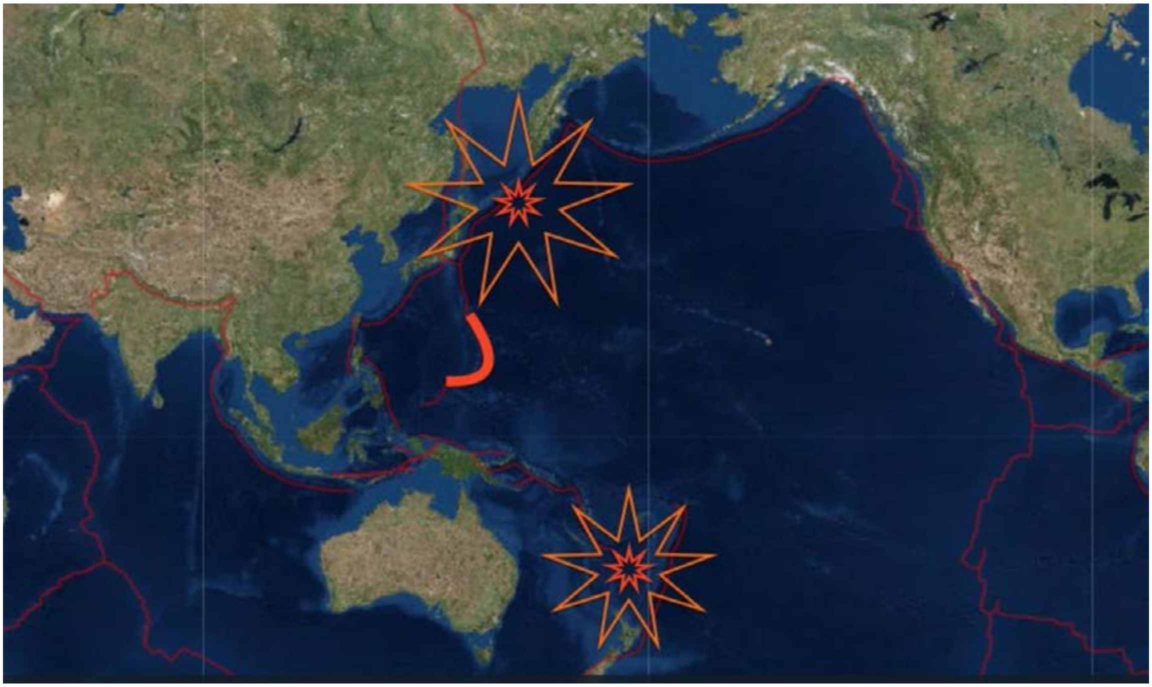
Luckily, there is one way to monitor every super-lithospheric (above ground) risk factor at the exact same time, and this data is not only readily available in usable format, but there are active forecasts of them at all times- Earthspots, the pressure cells of Earth. At these locations we know the GEC is strongest, connecting all vertical sectors of the atmosphere, telling us where any excess current is most likely to be found. **Just like sunspots and the bright umbral magnetic fields on the Sun, Earthspots tell us where the current is flowing in Earth's atmosphere, and potentially the ground as well.**

The atmospheric half of our location model uses Earthspots, with the only addition being recognized OLR anomalies from the papers listed earlier. The second half of the location model is sub-lithospheric (below ground). After studying the foreshock patterns to large earthquakes, it was determined (by community member Scott Windbiel) that deep earthquake foreshocks are, in general, present far more often before large earthquakes than shallow foreshocks. Since that time, we have further constrained the magnitude and depth requirements for many different regions across the globe. We call these deep events "Blot Echoes" to honor Claude Blot, who long-ago envisioned using deep earthquakes to forecast volcanoes.

The combination of these sub-lithospheric and atmospheric factors is used by our model every day to determine places where large earthquakes are more likely to occur. The 10 - 15% of Earth's fault system most at risk on a given day in our model is based on the regions that are showing the strongest signals above and below the ground.

To learn more about the model itself, including both reading and video learning options, you'll want to refer to the resources at QuakeWatch.net.

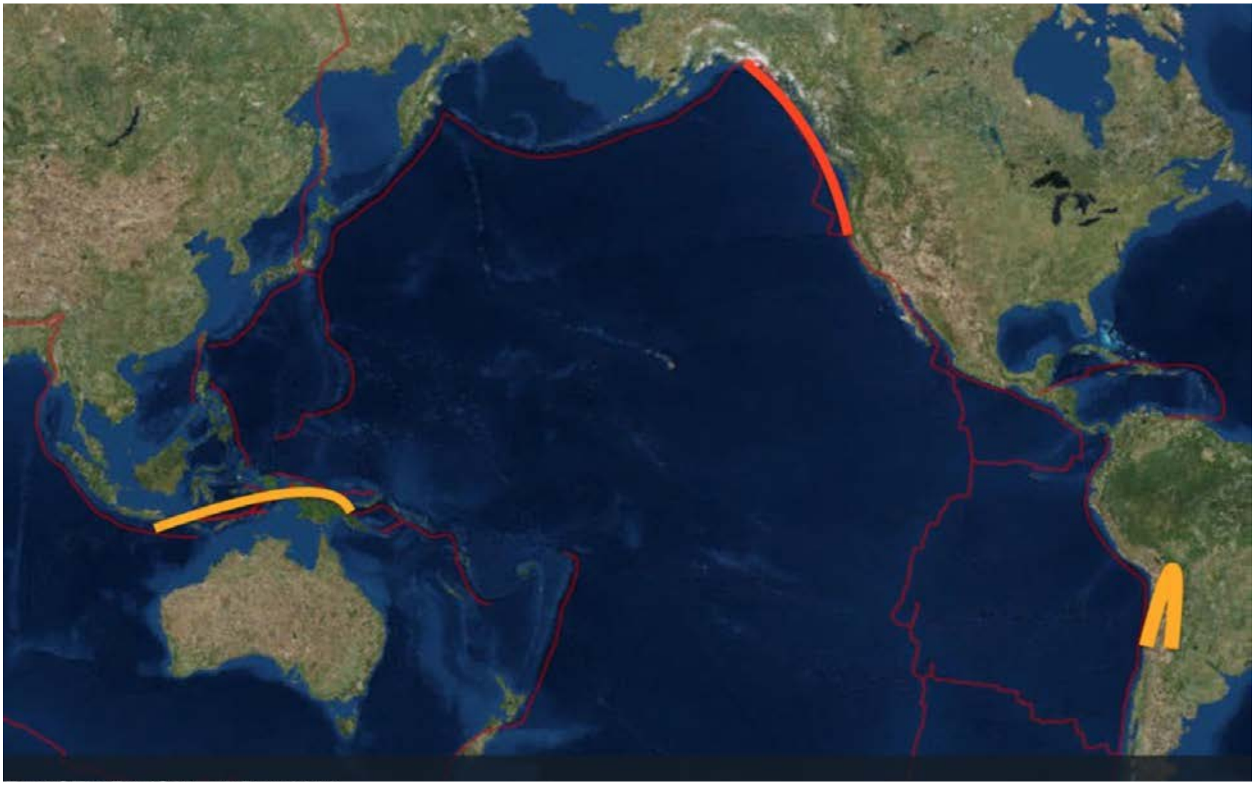
The Disaster Prediction App, not only tracks and sends earthquake, solar flare, geomagnetic storm and space weather health alerts, it has programs tracking blot echoes and atmospheric signals related to earthquake forecasting.



Above: The risk map posted by the App early on November 11, 2016.

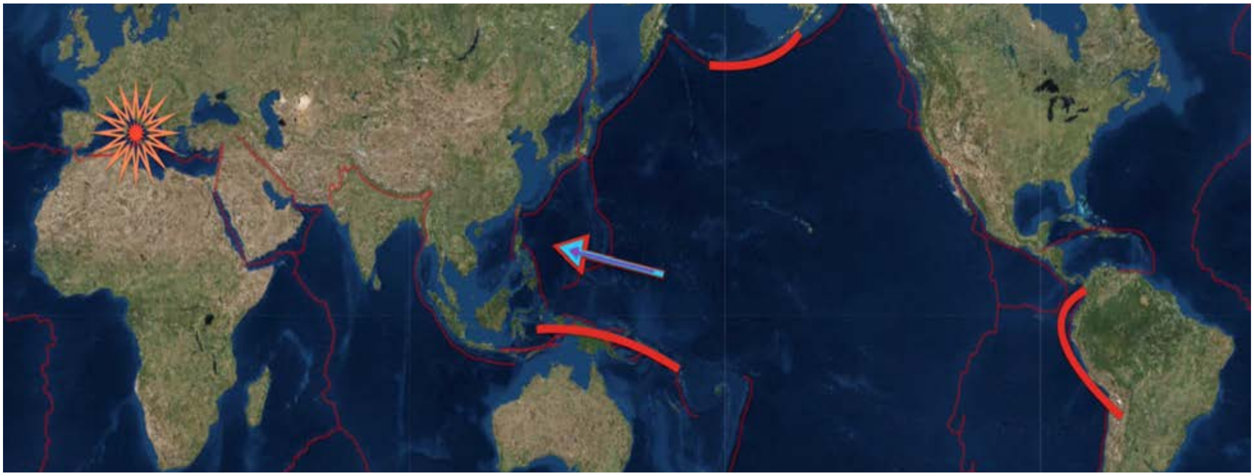
Below: The two large earthquakes that struck in the following ~48 hours.

This risk map was posted the morning of December 8, 2016. Hours later an M6.6 struck off the coast of California at the Mendocino Junction (southern tip of the red line). Red alerts for the United States are exceptionally rare, especially because…

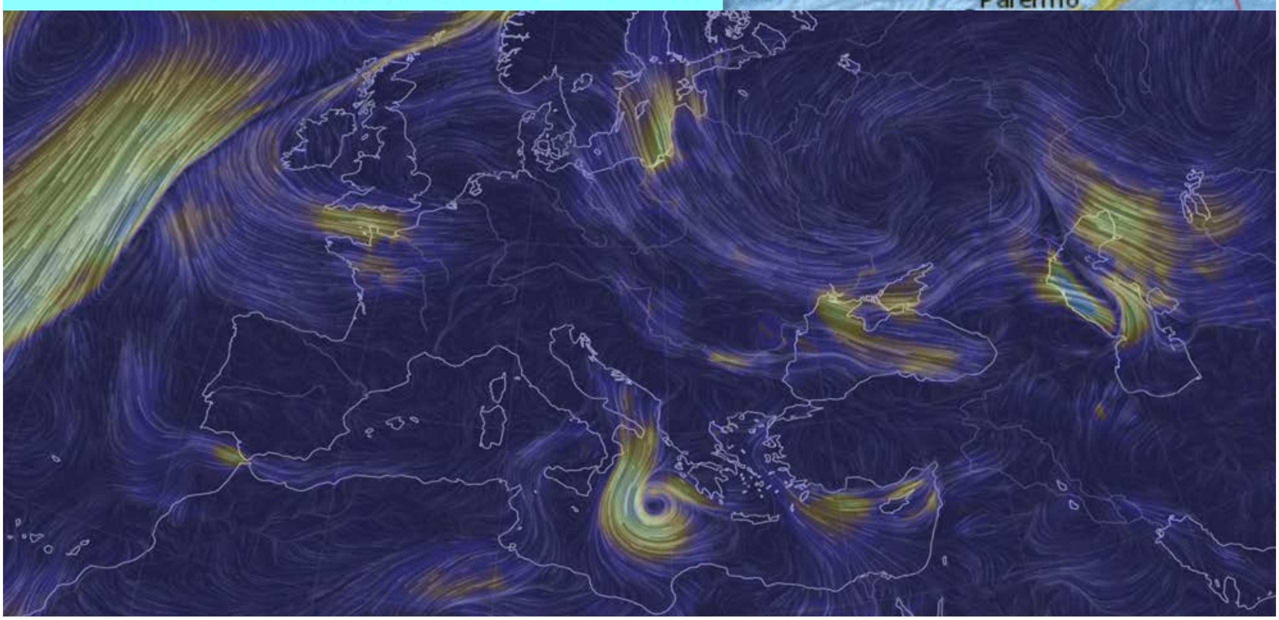


THERE ARE NO BLOT ECHOES IN THE UNITED STATES. So, we had to be pragmatic. When small earthquakes began migrating from Mexico to Nevada and towards the junction, with a strong storm overhead, it was almost too obvious.

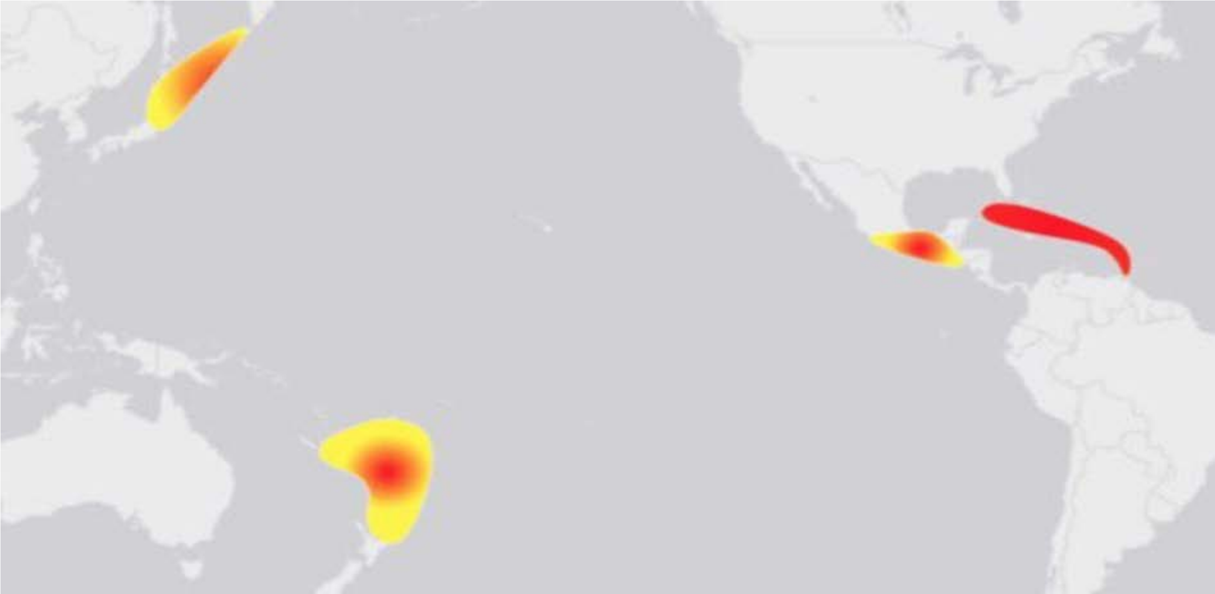
LEFT - Migration of foreshocks from Mexico directly to the region struck by the M6.6. *RIGHT* total Cloud Vapor overlay from this time, via Earth.nullschool.net, showing a strong low over the earthquake epicenter.



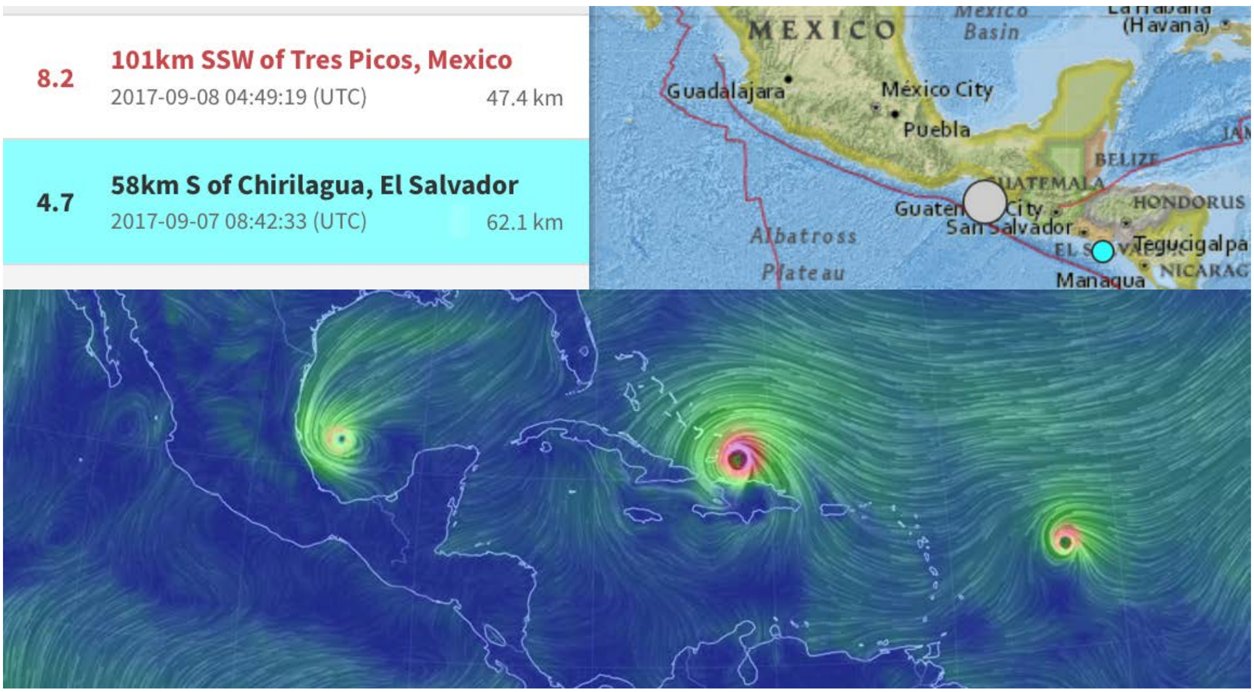
The image above was posted October 29th, 2016- fairly broad alerts spanned the ring of fire, but the focus was meant to be on Italy. October 30th- an M6.6 struck central Italy. As seen below, focus was driven by Blot Echoes and a strong storm near the fault zone.



The alert zones for September 8, 2017 were posted the night prior; it covered a few small alerts in the ring of fire and a larger alert for the Caribbean (image below)



The M8.2 earthquake in Mexico on September 8, 2017 occurred in the dead center of the red alert in the southern part of the country. Below we find the Blot Echo and atmospheric disturbances at that time- Earthspots show why the Caribbean was on alert.



The largest earthquake of 2019, a M8 in Peru on May 26th, was preceded by a flurry of Blot Echoes. The large gray circle above the word “Peru” is the M8 earthquake, and all but two of the other gray circles is a blot echo that struck in the time leading up to the event.

Here is a basic statistics list of the largest events since we began forecasting:

Largest ~20 Earthquakes During Real-World Testing (Since October 15, 2016)

THE EARTHQUAKE PREDICTION CENTER @ QUAKEWATCH.NET - THE DISASTER PREDICTION APP

Average Alert Zone Coverage: 10% of Global Faults (10% of Ring of Fire)

Success Rate by Energy Release: +90% of Energy Released (This Sample)

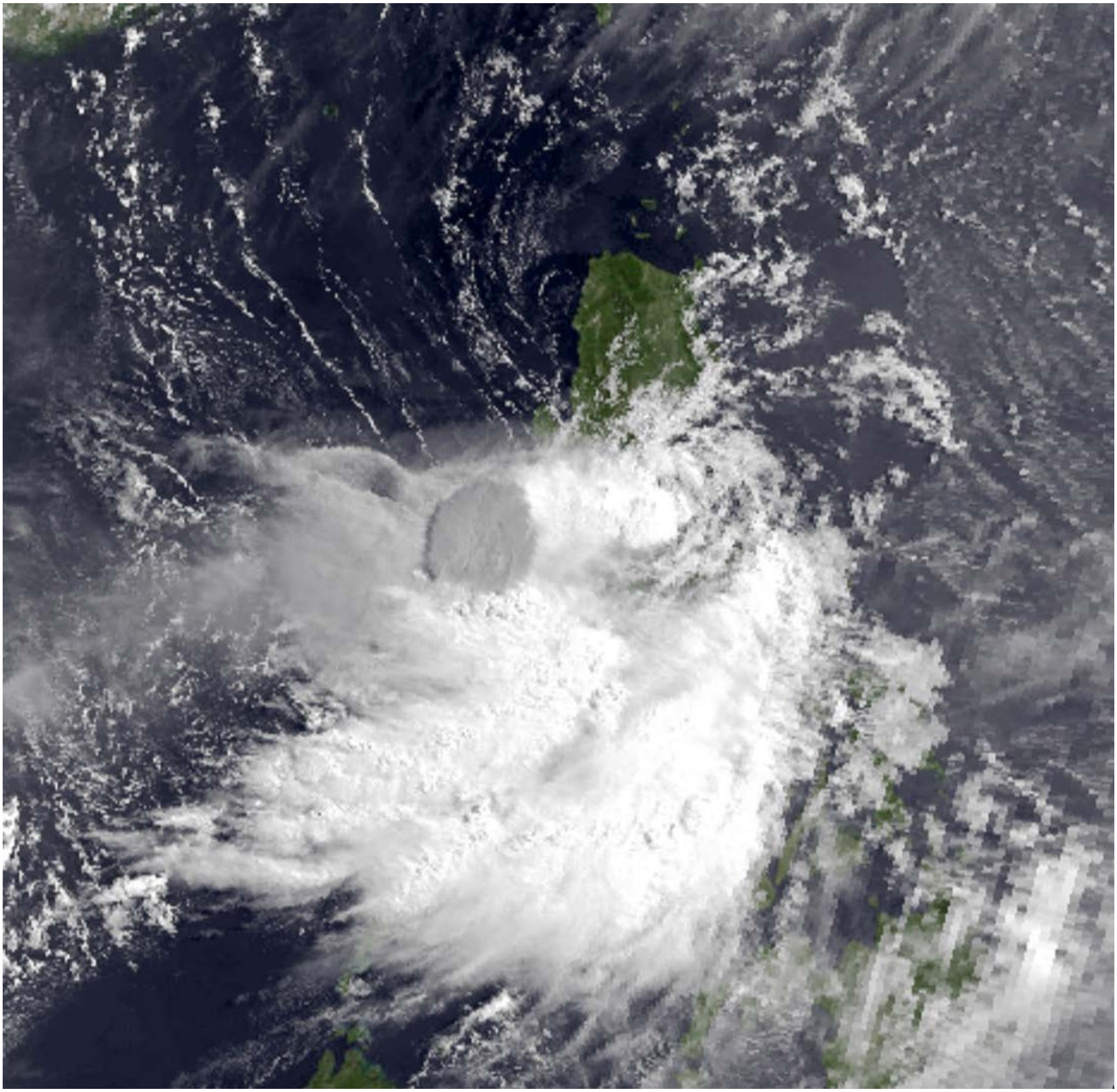
Status: Informational Only, Not For Official Action

Size Rank	Mag.	Date	Location	≥2 Risk Factors
1	**8.2**	**September 8, 2017**	**Mexico**	**Yes**
1	**8.2**	**August 19, 2018**	**Fiji**	**Yes**
3	8.0	May 26, 2019	Peru	**Yes**
4	7.9	January 22, 2017	Papua New Guinea	**Yes**
4	7.9	December 17, 2016	Papua New Guinea	**Yes**
4	7.9	January 23, 2018	Alaska	**Yes**
7	7.8	November 13, 2016	New Zealand	Yes
7	7.8	December 8, 2016	Solomon Is.	Yes
9	7.7	January 28, 2020	Jamaica	No
9	7.7	July 17, 2017	Russia	Yes
11	7.6	December 25, 2016	Chile	Yes
11	7.6	January 10, 2018	Honduras	No
11	7.6	May 14, 2019	Papua New Guinea	Yes
14	7.5	February 22, 2019	Ecuador	Yes
14	7.5	May 14, 2019	Papua New Guinea	Yes
14	7.5	September 28, 2018	Indonesia	Yes
14	7.5	February 25, 2018	Papua New Guinea	No
14	7.5	December 4, 2018	New Caledonia	Yes
14	7.5	March 25, 2020	Russia	Yes

The top two events in the continental United States were both successfully forecast: M6.6 in California, December 2016; M7.1 in California, July 2019

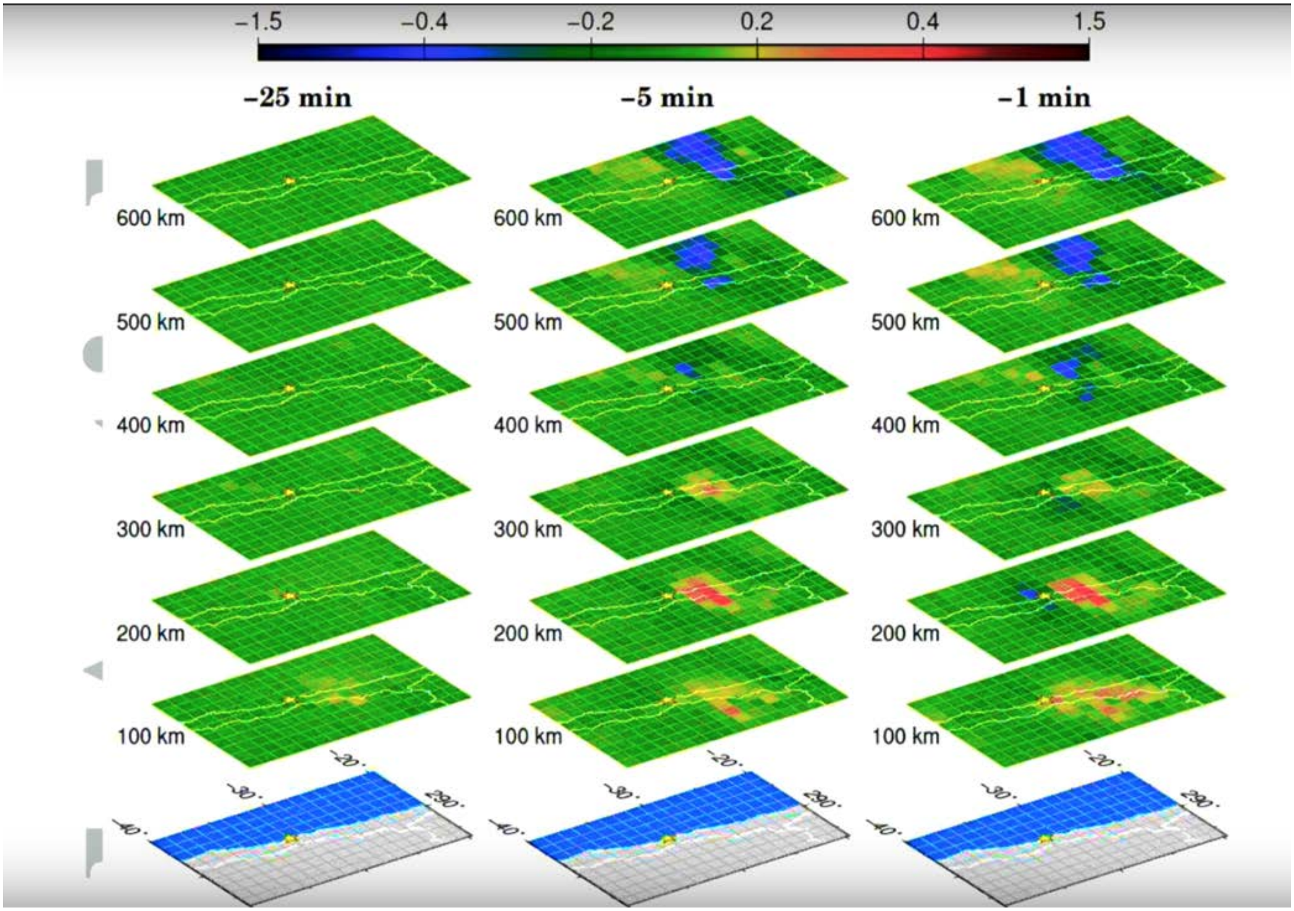
While human forecasting remains in progress at QuakeWatch.net, programmers are currently working to automate the system for exactly this level of real-time alert capability. Let's see some more fun examples:

A blast from the past.



Typhoon Yunya, with its gorgeous display from NOAA satellites marked by a large gray circle near the northern part of the storm. That gray patch is the eruption cloud of Mt. Pinatubo in 1991, the largest volcano eruption of the last century.

One more note from history: The August 2011 Virginia M5.8 earthquake that damaged monuments in Washington, D.C. was felt across more than a dozen eastern states. It was centered on the line of Hurricane Irene, which took a rare path over the region less than one week later. A powerful Earthspot and an ultra-rare quake in the same area. Relevant images below:



He and Heki, Three-Dimensional Tomography of Ionospheric Anomalies Immediately Before the 2015 Illapel earthquake, Central Chile, JGR, Space Physics 2018

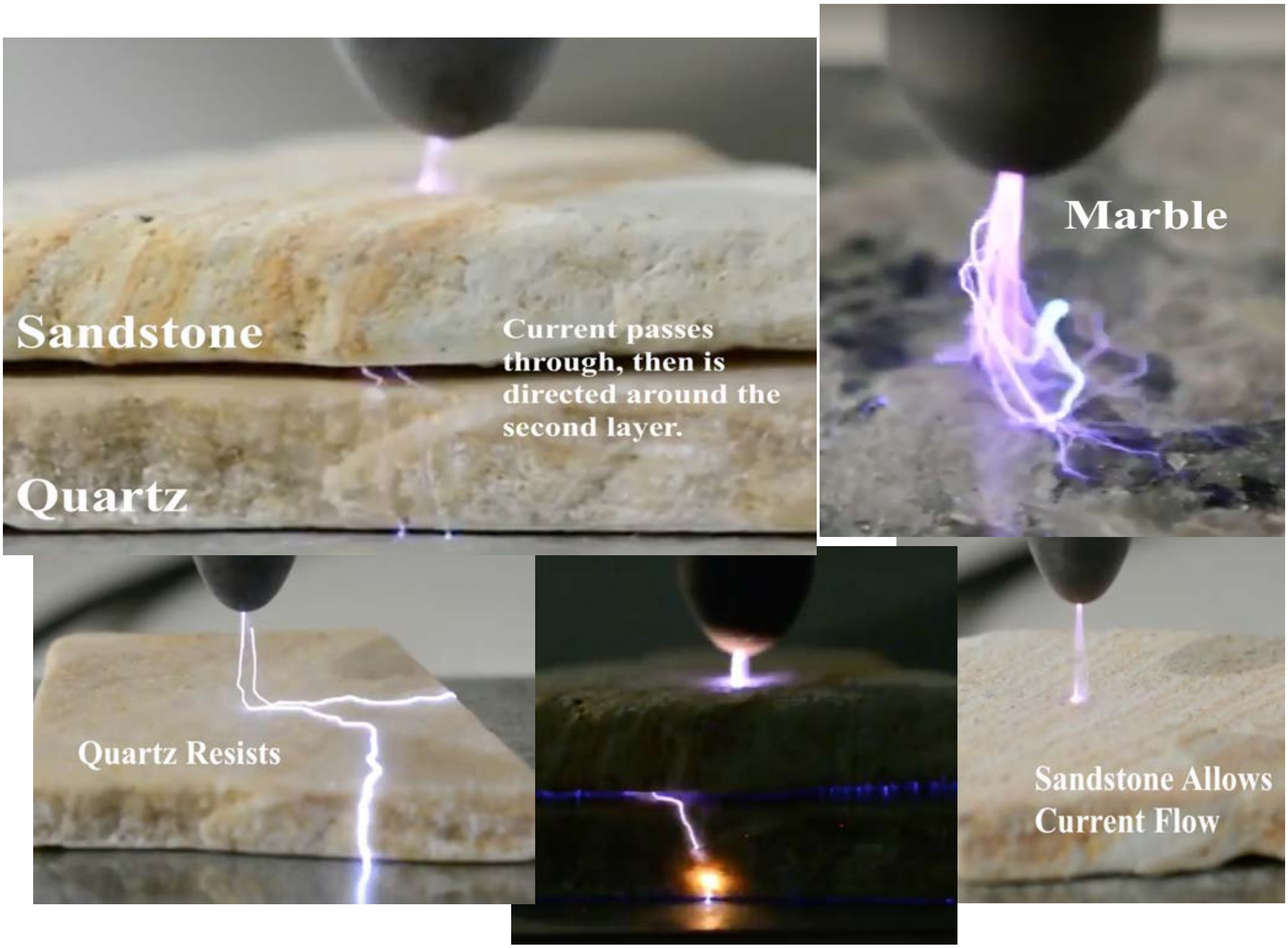
In September 2015 a M8.3 struck Chile. This event occurred under ***high*** pressure, with few foreshock warnings, and therefore would not have been forecast by our model. However, a strong groundward current (expected under high pressure) was forced by ionospheric electric fields directly down on top of the earthquake zone in the few minutes before the earthquake, connecting the circuit (He and Heki, 2018). This groundward current likely utilized the conductivity channels described for the ionosphere-to-ground surge pathways described by Borovsky 2017 (Section 5.4).

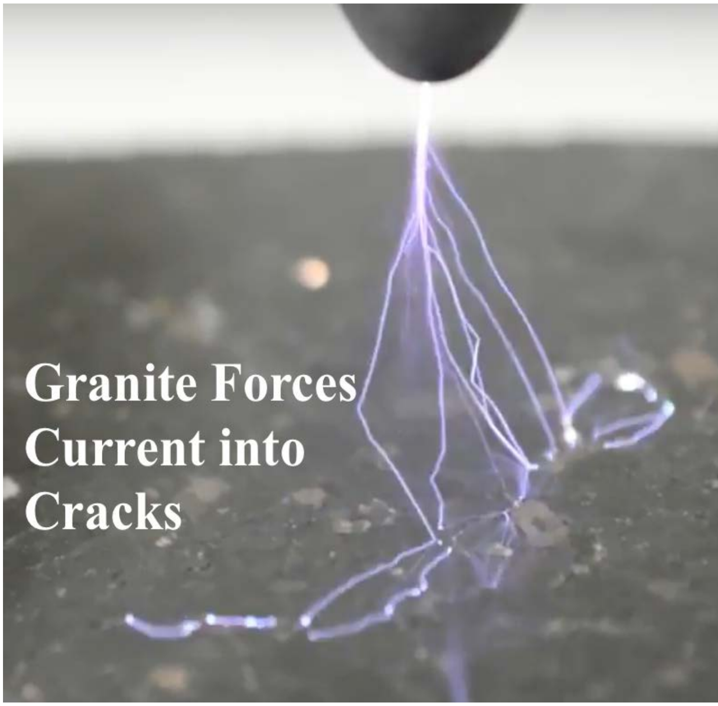
While not part of our model, this shows one area of potential improvement, and it involves charged material in the global electric circuit connecting the ionosphere to the ground. Commenters have noted that the current does appear to begin to return upward in the final minute, as shown by the blue patch on the -1 min/200 km image and the yellow in that position at the highest layers, and therefore it merely released too quickly for modern data and analysis to catch. Minding the fact that such suggestions are complimentary of our model, **it is impossible to deny the EM signature we look for is present in the final minute before the earthquake.** Only localized detectors could have caught this in time to warn anyone, and it would have been about a 1-minute warning; the satellite and distant detectors of most precursors are minutes behind “real-time”, and so looking at the charging-up nature of this pressure/GEC scenario works best. We *have* added this high pressure/GEC+ situation to our models for Chile and Argentina starting in 2020.

How do we know what Earth's energy does when it gets to the ground? We Tried It!

Understanding the process by which Earth's electricity triggers ground changes needs no time to work through the red tape of academia, you just need your eyes. The images on the following pages show how the circuit will bend, accumulate, and transfer through and around different rocks based on their composition and water content.

The following collages are produced from images taken by Billy Yelverton Jr. in his lab. These are arc-discharges and glow-mode plasma (for visibility) but on Earth, the plasma is in 'dark-mode' while still very much flowing in currents.



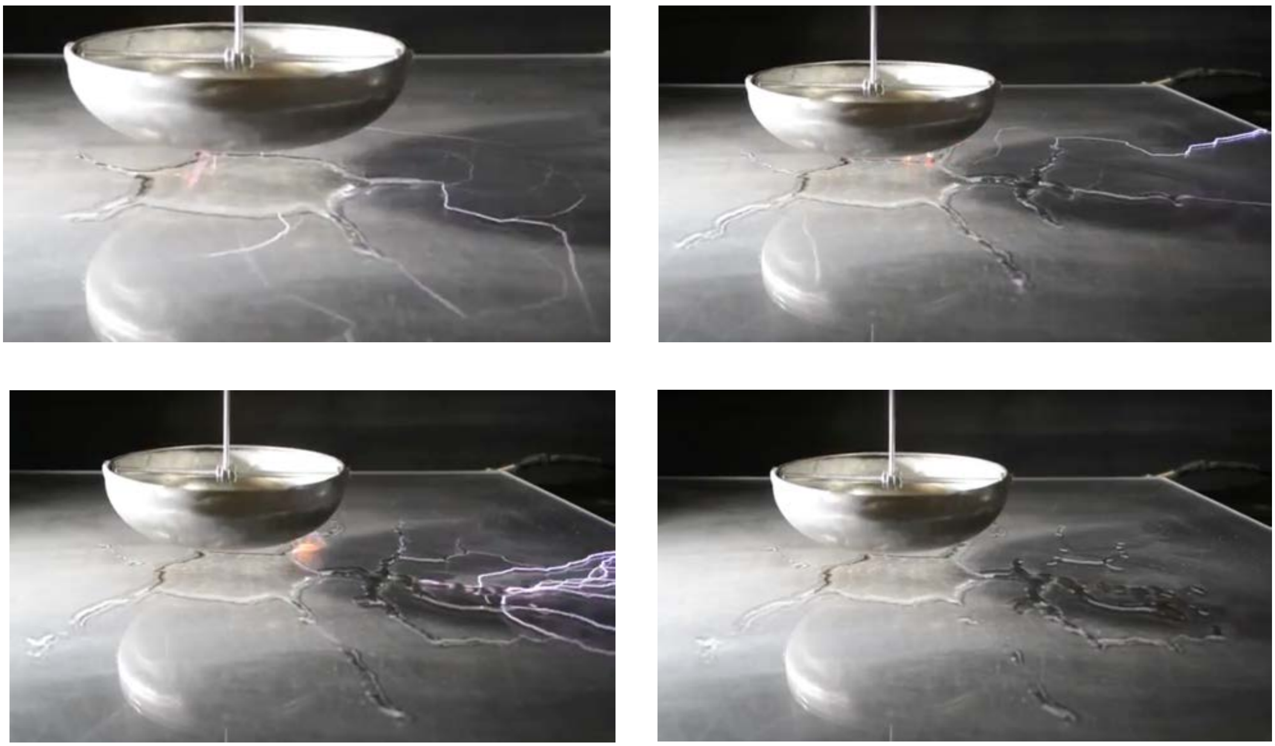


ABOVE: (Left) Current into granite. (Right) Cracks in granite become illuminated with plasma.
BELOW: More examples, with the lights off.

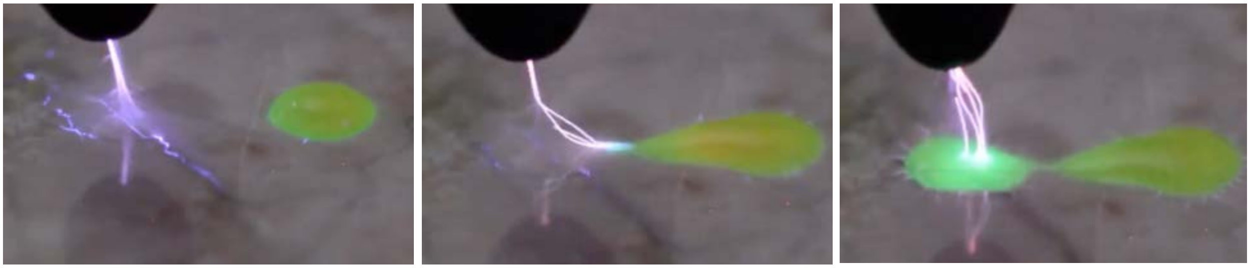
Water is very abundant in the crust and further below. It is estimated that an entire ocean's worth of water is hiding in the mantle. How does water in the ground create a push/pull over large areas when following the electric current?

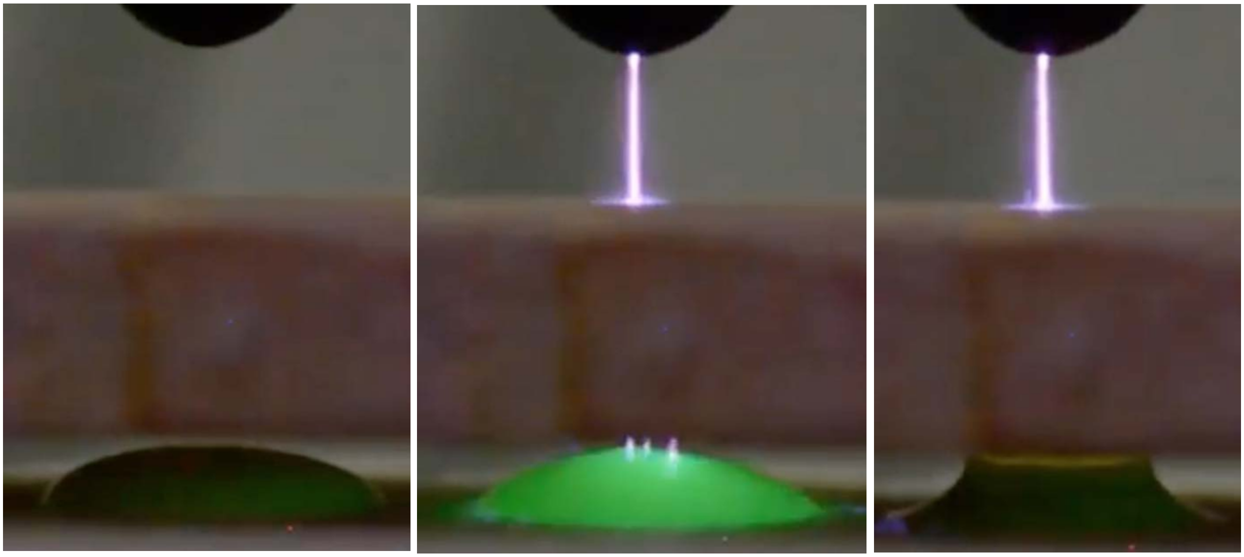
ABOVE: We begin pumping current down into the water on the left, sitting atop an insulator to induce lateral current flow (like the crust). The current quickly begins exiting the water in multiple places on the right, and the water begins to follow.

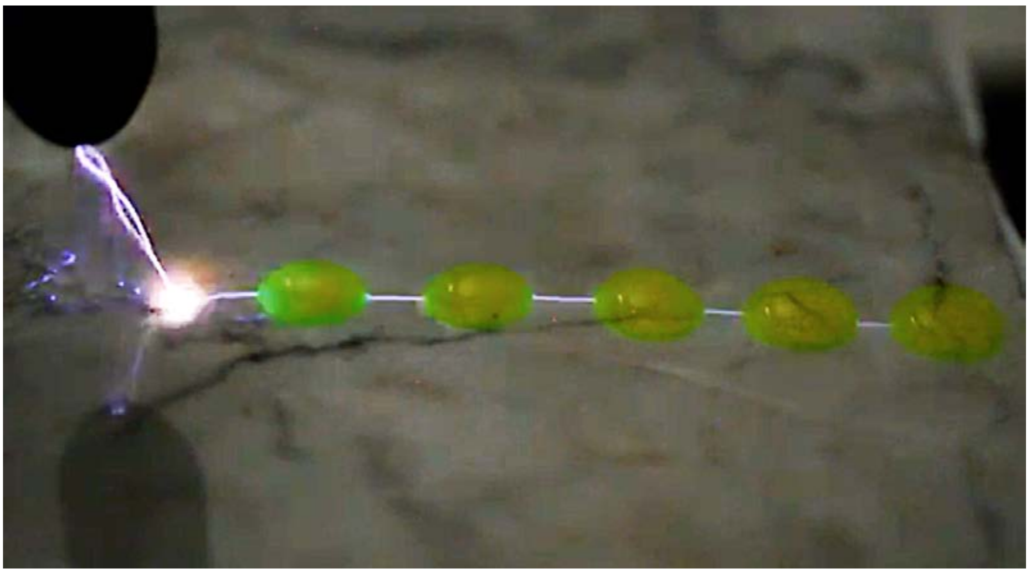
BELOW: The water continues following the current, creating a better pathway for more to flow with it. The water may be permanently displaced by the current (bottom, right image) even after the current disappears.



In these images the top two lines are sequential, left to right. The top line shows salt water with pyranine, sucked into the current. In the second line, the water is between rock plates, and when hit with the current it defies gravity and pushes up. In the bottom image we see that the breadth of effect is based on what is nearby, and that electricity *really* loves salt water- complete attraction.







Imagine what will happen to groundwater, trillions of tons over thousands of miles when it is hit by these currents. Remember, the GEC current seeks the path of least resistance (fault lines); this delivers major force, at the right place.

Among the hundreds of people across the world learning to predict earthquakes, one has stood out above the rest. Terrance Allen, California, USA is perhaps the most prolific earthquake forecaster in the world, he uses the Blot Echo/GEC system, and forecasts at QuakeWatch.net among the growing number of Blot Echo/GEC model forecasters. Growing up in California meant he was no stranger to earthquakes, and the memory of the Northridge earthquake in 1994 left an indelible mark on him.

As a fisherman he had been using pressure maps for years, and when he tried to apply the model to something he was familiar to seeing, his unintended training paid off:

“My first three ‘test forecasts’ were successful so I continued on.” Indeed, he has forecast dozens of M6+ earthquakes and five M7+ earthquakes. “It all hinges on the data that is in front of you,” he said.

“Almost all of my earthquake forecasts start with the Sun and the coronal hole influence. Understanding when these coronal holes will influence earth’s geo-space allows me to forecast the timing and magnitude of the larger events. From that point, I look to determine potential locations for where that energy will manifest- examining low pressure cells, the strength of these cells, where they are moving and identifying how much high pressure is around them.
At the same time I am taking into account the earthquake activity around the globe and I am able to cross reference the OLR data anomalies with storm systems. Often these storm systems can cross fault lines and trigger quakes so this is taken into account. We also look at the deeper, smaller earthquakes (Blot Echoes) to identify where the underground energy is trending/moving (directionally).”

Terrance routinely demonstrates that long-term Blot Echo trends can be as useful as short-term ones.

“As technological advancements are made in the field of earthquake prediction, we understand and hope that a day comes when these events are able to be forecast with accuracy and precision. This will truly save lives and be a blessing to humankind.”

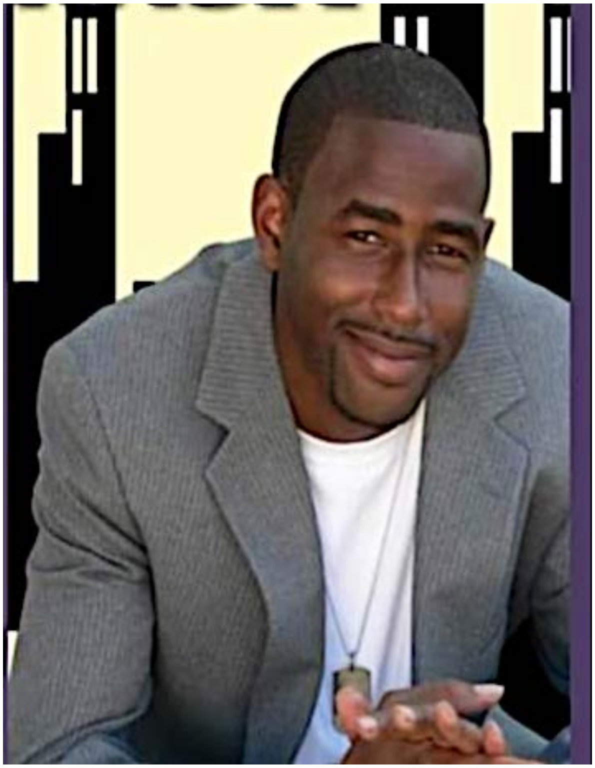


Image: Terrance Allen

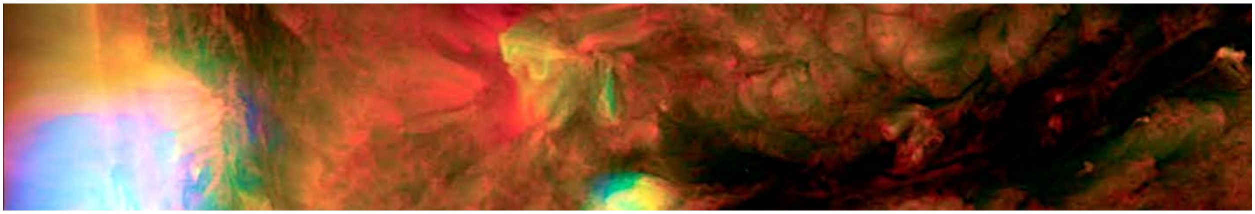
Ancient Egyptians told of the god Apep, the enemy of light/truth/order, the lord of chaos, born of the sun's (Ra's) umbilical cord, the cause of great earthquakes and thunderstorms, and a natural consequence of the sun's (Ra's) ignition (birth). Apep is most described as a giant snake, much like the serpents worshipped in China and South America.

This is just one story in Egypt about terrible days brought about by the sun.

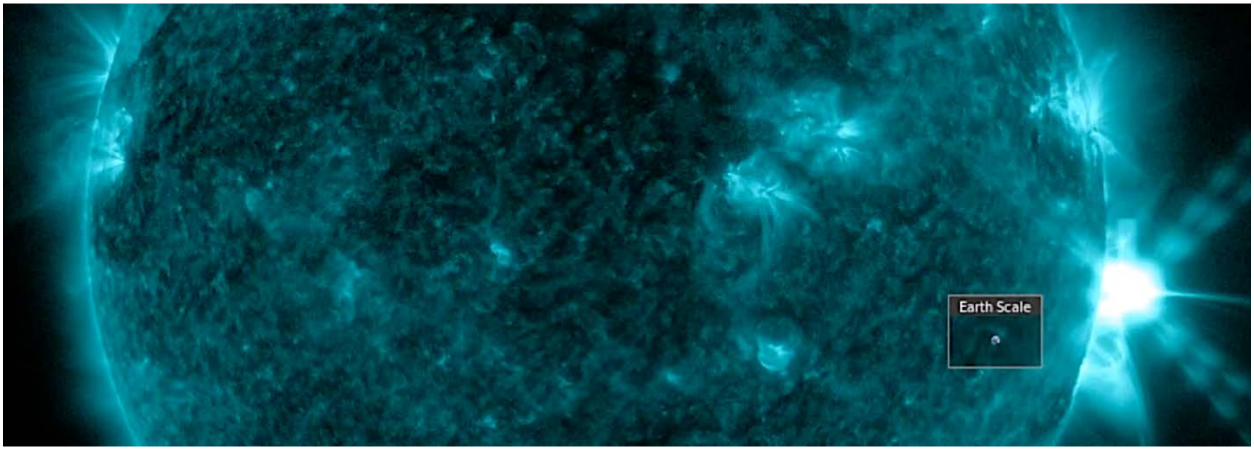
Shiva, the destroyer, is connected with the sun as The Red One. Ancient Greece contains stories of different looking sun's and different eras of Earth defined by them. The bible describes the sun going black. More than one Egyptian pharaoh identified with a black sun. To end the Earth with the biblical forecast of fire (instead of flood) would require either God's hand and a giant box of matches… Or the sun.

These are just a few of hundreds of stories from across the world, and across time, which insist on a duality to our star- that of a life-bringer and that of the destroyer. What if inadequate scientific understanding caused these events to be misinterpreted and incorrectly described by our ancestors?

This duality of our star *is* real, but it does not often present itself. Short-lived outlier events separated by centuries to millennia are a real part of living with a star.

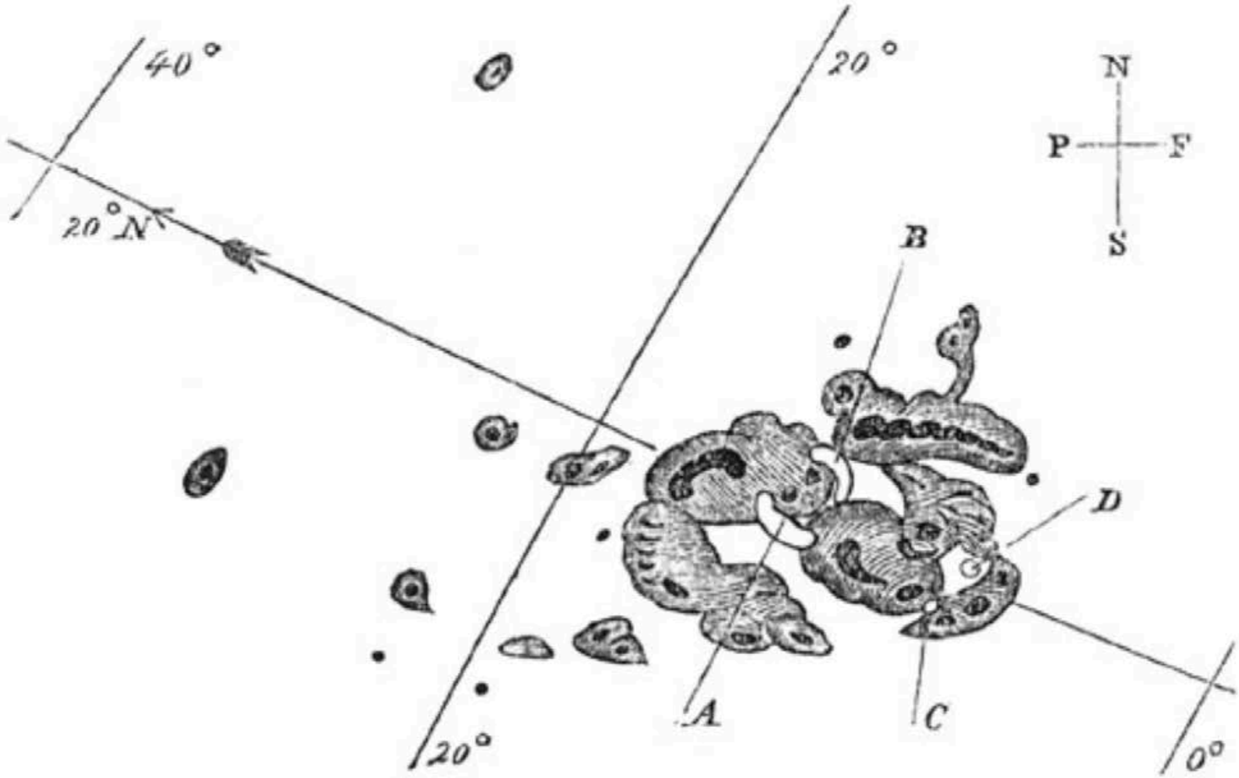


8.0 Extreme Solar Activity



8.1 Superflares

In Chapter 6 we mentioned two extreme solar events, The Carrington Event in 1859, and a stronger storm in ~775 AD, which is commonly called The Charlemagne Event. These are the lower and middle end of what are referred to as “super flares”.



This image was drawn in the year 1859 by Richard Carrington, depicting an enormous sunspot group in near-perfect Earth-facing position. It was drawn just before the great solar storm occurred. These strong events are generally measured in terms of a power unit called ‘Ergs’.

1 Erg = 600 billion electrons. Of course, this description is completely unhelpful.

Scaling up, one heartbeat is 1 million Ergs (10^6). The Japan 2011 M9.0 earthquake released ~10^{24} Ergs. Most of the sun’s flaring is in the 10^{26} to 10^{31} Ergs range. The Carrington Event is thought to be around 10^{32} Ergs, or about 10 times the usual maximum range. The September 2017 maximum solar flare was 10^{30} – 10^{31} Ergs.

The Big Bang is estimated to have been around 10^{75} Ergs. Powerful supernovae can be 10^{50} Ergs or more. The Charlemagne Event solar flare is believed to be about 10x stronger than the 1859 flare, or ~10^{33} Ergs. There is evidence that the sun can release a “superflare” (between 10^{34} and 10^{35} Ergs) on millennial timescales, perhaps once every ~2400-year Hallstatt cycle.

THE ASTROPHYSICAL JOURNAL, 848:41 (13pp), 2017 October 10 https://doi.org/10.3847/1538-4357/aa8e96
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CrossMark

Risks for Life on Habitable Planets from Superflares of Their Host Stars

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Received 2017 August 23; revised 2017 September 19; accepted 2017 September 20; published 2017 October 10

For the third time, we come to this article by Lingam and Loeb (above), but this time for its conclusive purpose, and not pieces of their results/research and implications. The superflare risk is real and is likely to be on the order of once every 1000 years, which would be more often than the Hallstatt cycle.

Do *Kepler* Superflare Stars Really Include Slowly Rotating Sun-like Stars?—Results Using APO 3.5 m Telescope Spectroscopic Observations and *Gaia*-DR2 Data

Yuta Notsu[1,2,3,10,11], Hiroyuki Maehara[4,5], Satoshi Honda[6], Suzanne L. Hawley[7], James R. A. Davenport[7], Kosuke Namekata[3,12], Shota Notsu[3,8,10,11], Kai Ikuta[3], Daisaku Nogami[3], and Kazunari Shibata[9]

Published 2019 May 3 • © 2019. The American Astronomical Society. All rights reserved.
The Astrophysical Journal, Volume 876, Number 1

The article pictured above is just one of the latest from the many authors who have been treating this question for years and coming up with only one answer: Yes, the sun can superflare. However, this paper represents a tremendous advancement of international cooperation. The University of Colorado researchers and those at the Japanese Astronomical Society deserve tremendous credit for championing these ideas over the last decade and more, and for coming together in this paper and others to demonstrate the maximum flare potential of our star. This international recognition of the superflare risk only became realized in 2018/2019.

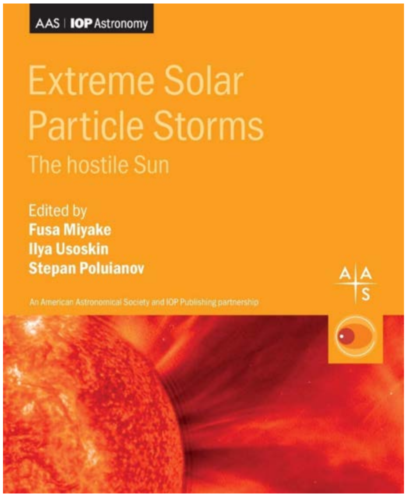
There is no way of knowing if the ~775 AD or 1859 AD event were part of a potential 1000 or 2400-year cycle, but the data on powerful events from 1921, 1989, 2003 and 2012 suggest that Carrington Level eruptions are more likely to be a smaller class, and on a centennial timescale of recurrence. The long-cycle blasts will almost certainly be much bigger.

If humans were to be so unfortunate as to see a super flare directed at Earth, the loss of the electrical age and likely breakdown of society is only the beginning of our problems:

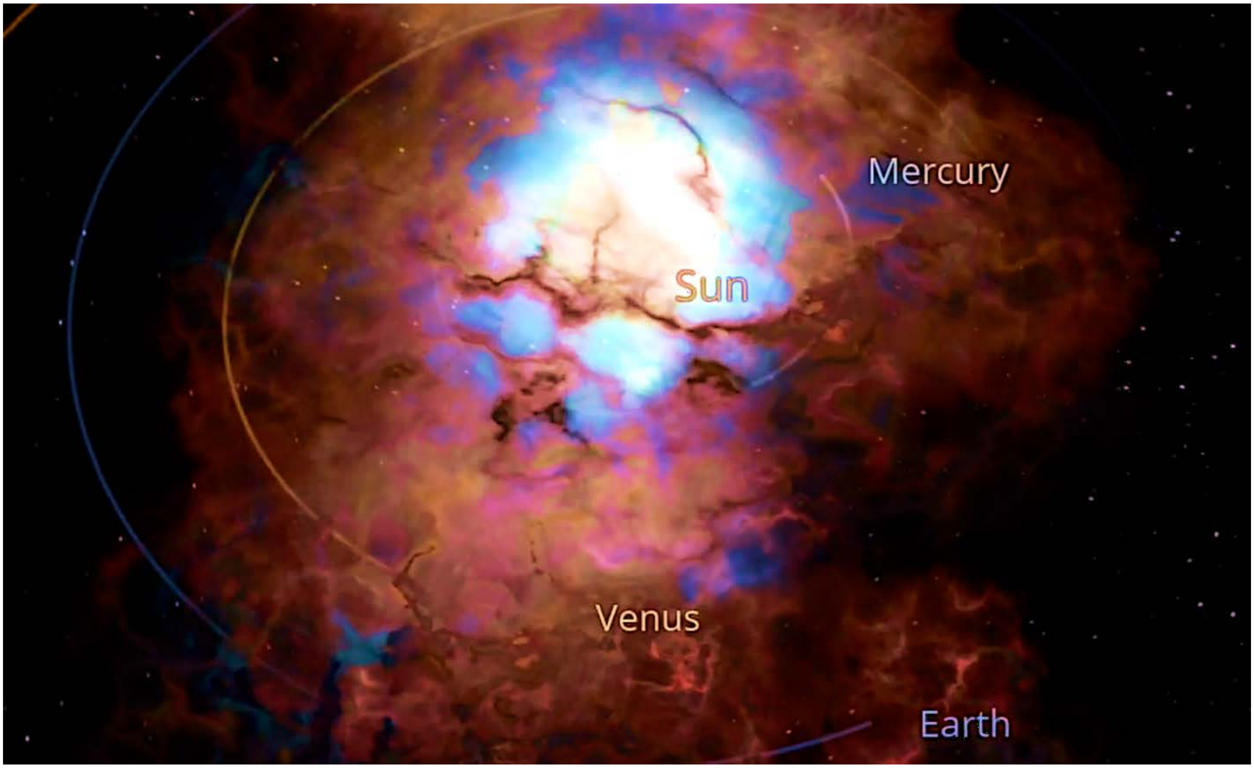
A. If the effects of decadal and centennial flaring can produce 3 to 7-degree changes in temperature (Lingam and Loeb 2017), then the super flare could produce 10 to 20-degree changes or more. These may not be so easily absorbed, spread and lagged, and could produce considerable climatological phenomena (like the ones described in Chapters 4 and 5, but to a great extreme).

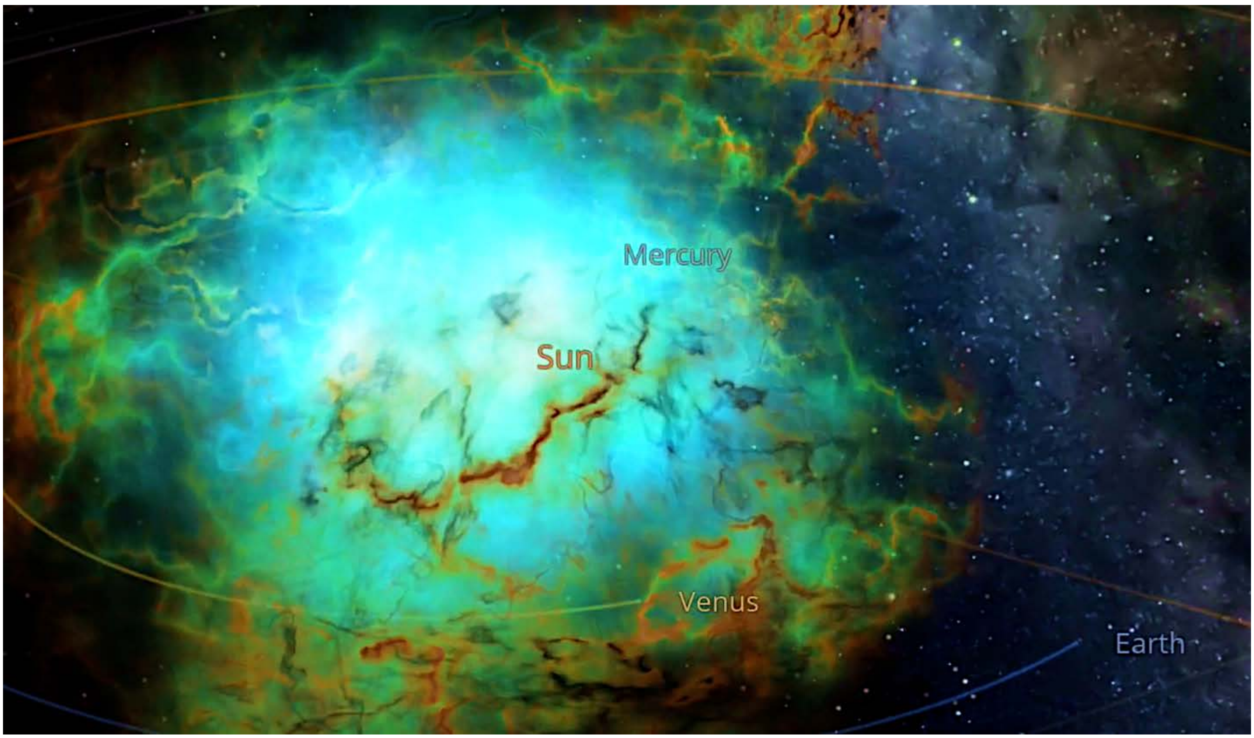
B. If a superflare should (rightly) make you think of extreme examples of the short-term solar forcing of the atmosphere and our technological age, then there are only two logical things to consider next: the health effects and the seismic effects. The induced electric current would be incredible, through our bodies, the crust and upper mantle. The magnetic frequencies will take on stronger emissions over broader ranges. From the light bulb to the tropical storms to the at-risk cardiac patient to the people near the San Andreas and Cascadia fault zones hoping they never see what *will* inevitably happen there again one day- it would be one of the worst days of our lives, followed by a Hollywood-like reset of the global society.

The premier advanced-level textbook on extreme solar flares and particle storms (pictured right) collects the state of the science as of 2019. The primary superflare conclusion is that the sun can reach energies of 10^{34} Ergs, or ~100x the energy of the 1859 event strength, which is currently modeled to be capable of crippling global power grids. Anything bigger- and we don't stand a chance.



The book also mentions that credible evidence exists that the sun may be able to exceed the 10^{34} Ergs strength maximum cited as the best-guess of the textbook authors/editors (Schrijver et al. 2012).

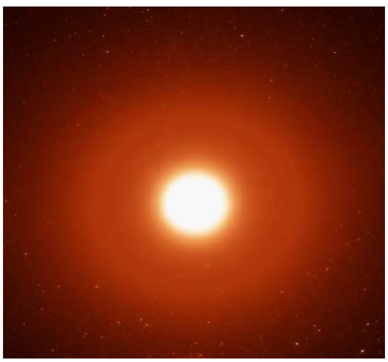
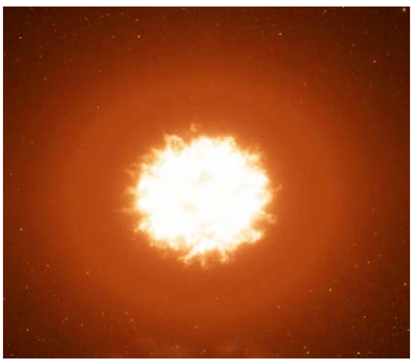

Mercury
Sun
Venus
Earth


Mercury
Sun
Venus
Earth

8.2 Micronova

This is not possible, right? It would be truly wonderful if that were the case, but it just cannot be certain, especially when there is indeed evidence to the contrary. There is a very real possibility that the sun is an ultra-long-period recurrent micronova star.

The first question that everyone should be asking is: What is a micronova? A supernova is a tremendous explosion of a star and is almost always the death of the star. A nova is a smaller release of the outer stellar shell or atmosphere and does not kill the star. A micronova is a small version of a nova.

1) Cosmic Blast Scale

A micronova is the name informally given to the type of smaller nova that may occur on the sun and other stars, with effects that are vastly different from a super flare. There *is* the release of a shell of ejecta, just not like supernova we hear about in the news and in movies.

Events by Luminosity Power (Ergs)

Cosmic Event	Luminosity	Notes
Most Solar Flares	**10^{26} – 10^{31} Ergs**	**Average range on the sun**
Dwarf Nova	**10^{30} – 10^{31} Ergs**	**As powerful as strong solar flares**
Carrington Event	**~10^{32} Ergs**	**Centennial-scale maximum flare**
Super Flares	**10^{32} – 10^{40} Ergs**	**Sun max. is likely ~10^{34} Ergs**
Micronova	**10^{33} – 10^{37} Ergs**	**Sun event ~10^{33} - 10^{35} Ergs**
Type 1 X-ray Burst	**10^{37} – 10^{39} Ergs**	**Huge luminosity, tiny ejecta**
Classical Nova	**10^{37} – 10^{43} Ergs**	**All may be potentially recurring**
Supernova	**10^{43} – 10^{50+} Ergs**	**"Hypernovae" are ~ 10^{50+}**
"Big Bang"	**~10^{75} Ergs**	**All energy and form in existence**

You might notice that micronova is not the smallest kind of nova on the list, and if we look past 'luminosity' and instead focus on shell ejecta size, then the micronova is much larger than type 1 x-ray bursts, which barely reach the kinetic power of normal CMEs from the sun. Dwarf nova are about as luminous as the September 2017 peak flares, and do not generally release much ejecta at all.

The key difference between these events is that flares comes from sunspot groups, while a nova is a total sphere event. The type 1 x-ray bursts usually come from compact pulsars, and models of their ejecta suggest the shell would barely affect Mercury if a similar size event happened at the sun. Of course, the 10^{38} x-ray luminosity of such a burst could literally melt the surface of the planet so the shell is a moot point, but that is a different story. The point is that tiny novae exist. In general, micronova will not break apart planets while classical nova on the larger end very-well could.

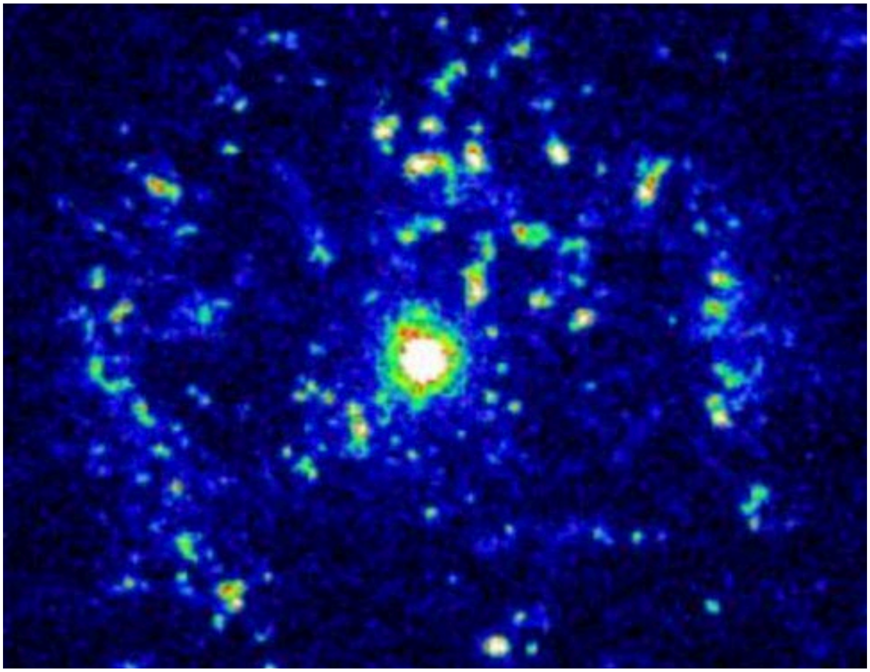
For the purposes of the sun, we are looking at a "recurrent micronova" with likely similar triggers to other known recurrent novae. Next question: What is a recurrent nova?

2) Recurrent Nova

One of the most sobering concepts to digest is the fact that astronomers believe that most if not all novae are recurring. Supernova can destroy a star, but if there is a star remaining it has the chance to nova again, and in fact we have seen a number of recurrent novae already in our relatively short (in astronomical terms) viewing of the heavens with modern technology.

In 1900, a relatively boring star named V2487 Ophiuchi had a dramatic brightening. It was a notable event but was considered relatively unremarkable in an era when telescopes were beginning to find numerous novae in the heavens. It erupted again in 1998, for the first time in 98 years, and now we know it will probably do it again in the latter half of the 21st century.

There are about a dozen recurrent novae known in the Milky Way, and one in the Andromeda galaxy. Modern telescopes cannot discern these events very well in other galaxies, and were it not for the high recurrence rate of the Andromeda event (erupts ~every Earth year) we might not have noticed. Of the ones we know about in the Milky Way, the known recurrent novae range from recurring every few years to decades apart.



The image above is of the famous “T Pyx” recurrent nova taken by the Hubble Space Telescope. You can see the shell of ejected material, as well as the remaining star in the center. T Pyx has had six nova outbursts since 1890. Astronomers believe that there are many, many more than are known, but that most have centennial to millennial timescales, or have too small of nova events for us to have yet noticed. Many of the novae we have seen will erupt again someday and make the list of recurrent events. Many have not been seen going nova yet and will not be seen for potentially thousands of years more. When we see them, it could be centuries to millennia more before we know of their recurring nature.

The current explanation for recurrent novae is a scenario where an accreting binary star is close-by and shedding material down onto the other star, causing a thermonuclear reaction in the stellar atmosphere, over and over again. However, the dominance of this hypothesis has not been confirmed in the least. While many nova events likely occur that way, they have not visually confirmed the presence of a binary at any of the recurrent novae, and the same is even true for many of the supernova said to occur the same way.

3) Potential Micronova Triggers

Nuclear Ignition of White Dwarf Stars by Relativistic Encounters with Rotating Intermediate Mass Black Holes

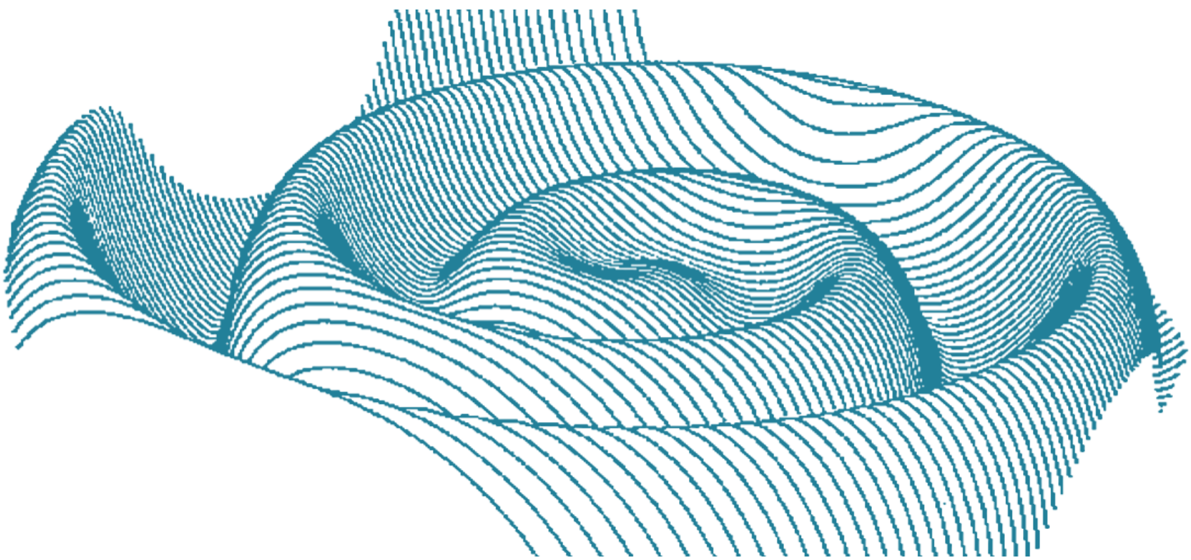
Peter Anninos[1], Robert D. Hoffman[1], Manvir Grewal[2], Michael J. Lavell[1], and P. Chris Fragile[3,4]

Published 2019 November 8 •

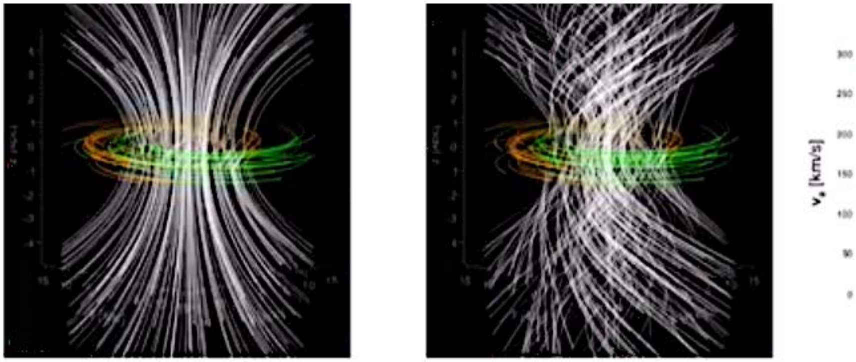
The Astrophysical Journal, Volume 885, Number 2

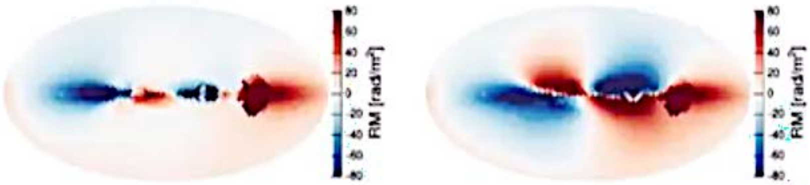
In addition to the accretion mechanism, which causes a chain reaction in the star's atmosphere, there are also mechanisms for plasma instabilities to trigger the same kind of outburst. In the paper shown in the image above, it was demonstrated that such a plasma instability may be a good explanation for the nova events that don't seem to have visible binaries. While this study used a dark binary – the 'black hole', the plasma instability may be imparted in a number of other ways. These instabilities could also disengage a stellar outflow (opposite effect from outburst) which would lead to particle accumulation in its atmosphere, and the same thermonuclear runaway accumulation process. The plasma instability has two nova tools in its tool box.

The sun is in the interesting position of potentially being subject to both of those trigger mechanisms at the same time- the accretion and the plasma instability. This double-trigger could potential come cyclically and have its foundation at the galactic scale. In the image below, we see the same figure that we saw in Chapter 1 – the heliospheric current sheet, the rippling, wavy electric field boundary between the north and south solar wind magnetic field sectors. This is a critical form around the sun, most stars, and indeed, the galaxy itself.

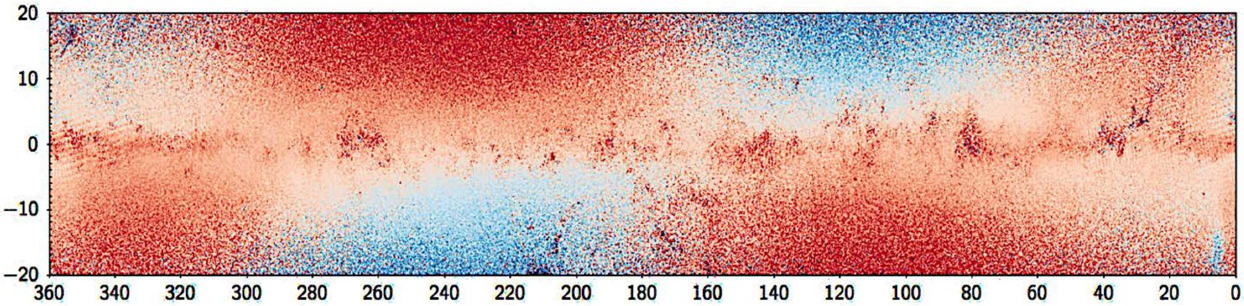


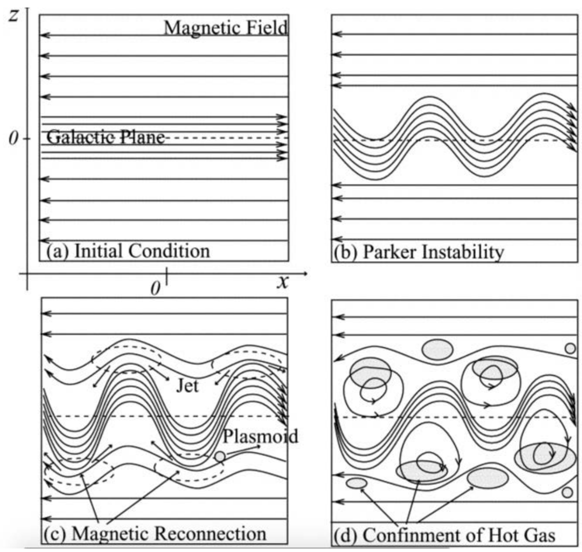
The images below show a few of the ways in which the galactic magnetic fields are now widely shown to have similar polar field structure perpendicular to a rippling disk, just like we see at the sun. This is almost certainly true of ALL spiral galaxies, if not all but the most irregular galaxies.





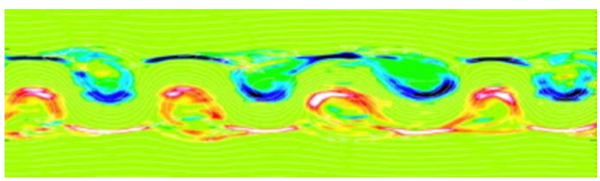
Credit: Above- Michael Unger/Glennys Farras EPS Web Conf 201 (2019). Below- E. Poggie et al. arXiv:1912.10471





The galactic current sheet electric field is indeed a massive parker spiral. Credit left and below:

Tunama et al. (2001) *Magnetic Reconnection Triggered by the Parker Instability in the Galaxy*



Next question: What does this wavy galactic sheet mean for the sun? We have to answer two other questions first. This part is relatively simple:

A. Is there a way to model the galactic sheet/field interactions with the sun in a way we already know?

> Many scientists are already modelling it like a scaled-up version of the solar system current sheet, so we can use that as our model. In the solar system, the sun's rippling sheet hits Earth every ~2 weeks, brings fluctuating solar wind density, a magnetic reversal in the solar wind fields, and can cause geomagnetic disruptions and induced electric currents. A solar-magnetic disruption and induced electric currents sounds like a recipe for plasma instability on the sun.

B. What would be different about the galactic sheet vs the sun's sheet?

> The solar system is relatively low-density. Gravity of the sun and planets, plus the powerful UV light and solar wind blowing outward from the sun for billions of years, has left our solar system very 'clean' – if we can put it that way. This is contrasted with the galactic plane, which contains the blown-out solar wind material, gases left over from star formation, and dust from countless novae over time.

So, at the galactic level, there is still the electric particle density event, and the galactic scale magnetic field reversal, but there is also a ton of junk (plasma, gas, dust) riding the galactic wave that is not found in the solar system.

The practical reality of these facts is the there is a large potential for material deposition into the solar system, providing the material accretion and accumulation mechanism that is thought to work at many recurrent novae. The electrically charged component of that accreted material, combined with the larger scale galactic magnetic field reversal, would provide a solar-magnetic disruption and induced electric currents through the sun, and since the sun is made of plasma, these electromagnetic effects could provide a number of plasma instabilities (for physicists: 2-stream, kink, Raleigh-Taylor, Parker amplification) which may satisfy the second trigger mechanism.

At very least, such interactions could have drastic effects on sunspot and coronal magnetic field activity, and recall that a plasma instability can go both ways- triggering or subduing. If the solar wind were to be subdued, the accretion mechanism comes into play, so all of these triggers begin to work together and feed off of each other when they are delivered by one galactic event.

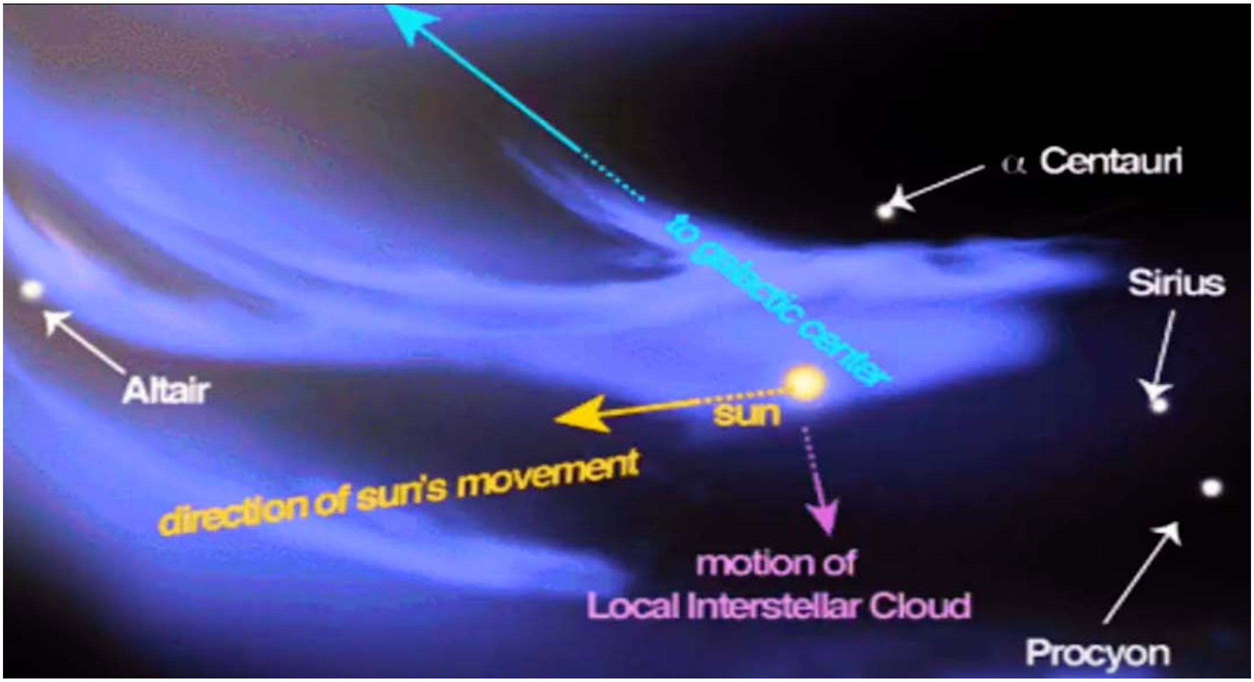
If you have ever heard the doomsday theory that our sun crosses the galactic "plane" or equator and something terrible happens, please realize that they simply misunderstand the placement of that rippling current sheet and magnetic reversal point in the galaxy. The galactic sheet ripples very high above and below the equator of the galaxy, just like the sheet in our solar system. There is absolutely nothing that happens when the sun crosses the galactic equator… unless the galactic sheet happens to cross the equator at that exact same place too. A star crossing the galactic sheet is barely beyond the most basic plasma science and nova astronomy, and it is disasterous.

So, this delivery of double nova-triggers from the galaxy… when do we expect that to happen?

Let’s go back to this scalable model from the solar system. The Earth takes 365 days to go around the sun, and twice during that period it crosses the solar equator (every 6 months). Yet, the sun’s current sheet is moving much faster, and hits Earth every two weeks – a much more recurring event.

The sun takes 250 million years to go around the galaxy, with millions of years between the hemispheric shift of the sun’s motion across the galactic equator, but how often does the galactic sheet cross the sun’s path?

That is an open question, but from some of the mappings of the nearby waves of dust and gases, the sun may be nearer to a dense region than we would like it to be. The image below is from NASA.gov; a dense galactic wave is about to (or has already begun to) sideswipe our solar system.



4) A Catastrophe Cycle Coming Together

One of the strangest aspects of geophysical science is the seemingly unexplainable nature of a cyclical magnetic excursion on the Earth. A magnetic excursion is not like the magnetic reversals that occur every few hundred thousand years- they happen much more frequently, and do not result in a reversal of polarity, but a flip and rapid flip back, such that the end result (geomagnetically) is the same as the start. The evidence suggests that they are true extinction level events, much more devastating to the biosphere than the longer-term events (Channel and Vigliotti 2019).

The last magnetic excursion is known as the Gothenburg event, and it occurred approximately 12,000 – 13,000 years ago. The Lake Mungo event was somewhere between 21,000 and 25,000 years ago. The Mono Lake event was ~31,000-37,000 years ago. The Laschamp event was ~ 41,000 – 48,000 years ago. There is evidence of events in the Vostok ice cores around 60,000 years ago, and in the volcanic flows from the Toba eruption period ~72,000 years ago.

There is a wide range of dating on some these events, but why? How could we have the isotope dating story so unclear/wrong? The image below is a recent paper that adds to the geophysical mysteries and might make those large ranges of time seem less unreasonable.

Geophysical Research Letters / Volume 46, Issue 12

Research Letter | Open Access

^{81}Kr Dating at the Guliya Ice Cap, Tibetan Plateau

Lide Tian, Florian Ritterbusch, Ji-Qiang Gu, Shui-Ming Hu, Wei Jiang, Zheng-Tian Lu, Di Wang, Guo-Min Yang

First published:29 May 2019
https://doi.org/10.1029/2019GL082464

The ice cap on the Tibetan Plateau was thought to be about 500,000 years old or older. These estimates were based on much more advanced dating techniques (supposedly) than carbon-dating, including both Chlorine and Oxygen isotopes. Then, this team used Krypton^{81} – a more difficult, but fantastically more accurate analysis. They now believe the upper age range could be as little as 15,000 years, which of course implies it could be much younger. Not only does this help show how little we know, but it might actually peg that ice cap to the last event ~12,000 years ago.

Another study recently dropped the age of an Australian crater by more than 100,000 years due to different isotope dating techniques. These are just two examples in a wide array of puzzling chemical signatures on the Earth. The *most* puzzling are the fission tracks found in the bones of surge deposits and microtektite glass beads, which show isotopes like Aluminum^{26} and elements higher in atomic number than Uranium! (Elements higher than Uranium are referred to as 'transuranic elements').

These require nova to be found here on earth from that time period; the meteorite needed to create a blast that big would have destroyed Earth completely- it takes THAT much energy. These isotopes populate the bones in great surge deposits from around the time of the Gothenburg excursion and previous events. These isotope laden masses of bone and plants and Earth, seemingly swept into a mashed-up bundle in some terrible event, are seen in various places worldwide. They also find the isotopes in microtektites (microscopic glass beads) found from the same time.

During the Gothenburg event, we not only had that great impactor that allegedly hit Greenland, but there is impact evidence in Chile, Syria and southern Africa, and yet also the glass beads from air-burst explosion (rather than impact) are strewn from North America to the tip of South America to South Africa, and are pegged to the same time period of the event. So, which is it? Could it be

both? Impactors cannot trigger a magnetic excursion. None of the craters are big enough to imply the heat needed to make nova-level isotopes, so we hit a wall there as well.

During the Gothenburg event, the Younger Dryas cold period began, one of the fastest-developing and dramatic portions of the last ice age. There is similar evidence of rapid (relative to previous) cooling in the older event evidence as well. Impactors *could* result in ice age conditions due to the dust and smoke blocking of sunlight, but this doesn't help us explain the excursion or the isotopes.

Next question: How do you get a magnetic excursion, a great cooling and ice deposition, increased impactors and airburst microtektites, extinction level events in the biosphere and isotope evidence of a nova… over and over again in a cyclical pattern?

The answer must account for ALL the evidence. A recurrent solar micronova does that.

Magnetic Reversal: A cyclical solar micronova that induces current all the way to Earth's core can cause in incredible event throughout the field-making regions of earth's interior. Remember, the sun can already touch the mantle with modern day space weather. It is well established that engulfing an object in an electric field can reverse the polarization/magnetism of the object. This can be envisioned here at the solar system scale, at the sun itself (with a plasma instability), and with the sun's effect on the earth.

Such a major solar event would finish the ongoing magnetic reversal, which *has* already begun due to an ongoing interaction with the galactic current sheet- it just takes a bit longer for those galactic physics to overcome the sun. We will examine the evidence that other planets are undergoing the same kind of shift as Earth later in this section.

Great Cooling: The evidence of tremendously rapid ice and snow deposition presents a geophysical mystery. In order to have this much snow and ice deposited in such a short time there must be a large amount of water in the atmosphere and a tremendous amount of cold. The problem is that to get that much water into the atmosphere requires a lot of heat, immediately before the tremendous cold. This seems impossible, until you realize that a solar micronova would provide the energy at the initial flash to increase evaporation, but the nova shell would cloud the inner solar system and upper atmosphere with dust. Even presuming that the sun rebounded to full luminosity after the micronova, the dust would reduce the sunlight enough to freeze an atmosphere already freezing due to the cloud production/light reflection (albedo) from the evaporated water. As counterintuitive as it might seem, a nova event can bring an ice age as easily as you can probably envision it scorching a planet.

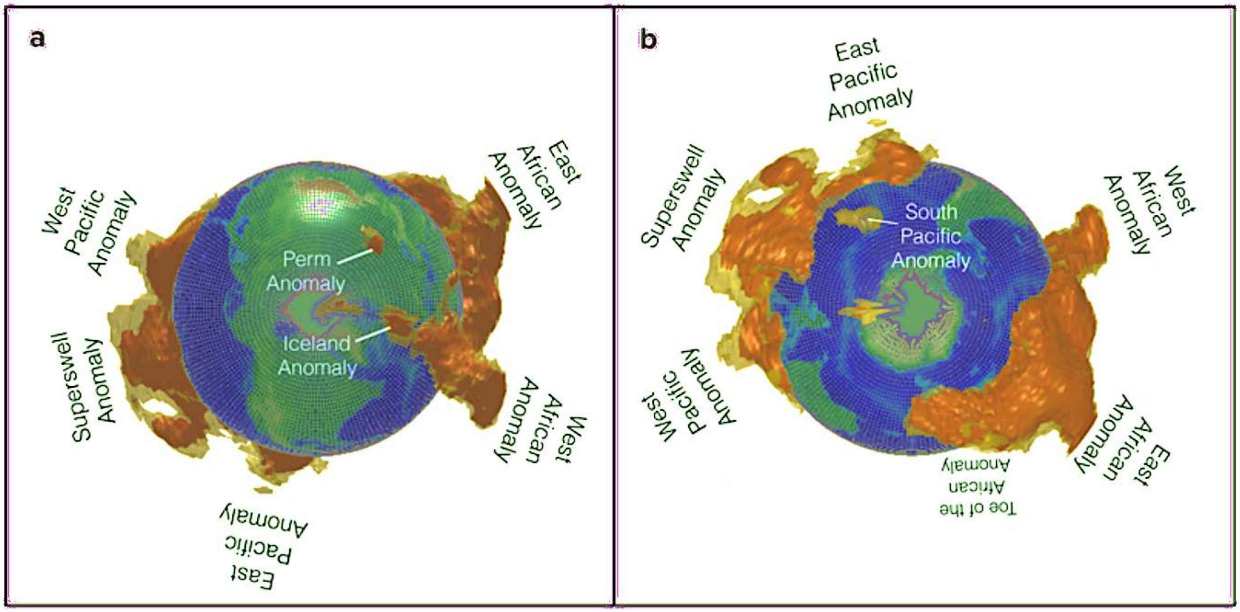
Impactors: The nova creates its own impactors AND microtektite glass beads (high silicon and oxygen content of most nova shells) out of its ejecta material. Both the existing meteors in the inner solar system and the cooled, congealed nova shell pieces could be tossed in earth's direction as impactors during this event, along with the microtektites.

Isotopes: If the solar micronova is the culprit, we expect nova-level isotopes. We also might expect them to create a confusing situation for those attempting to date geological features with these isotopes, especially when such a solar event is not a tool in the tool box for most of the field.

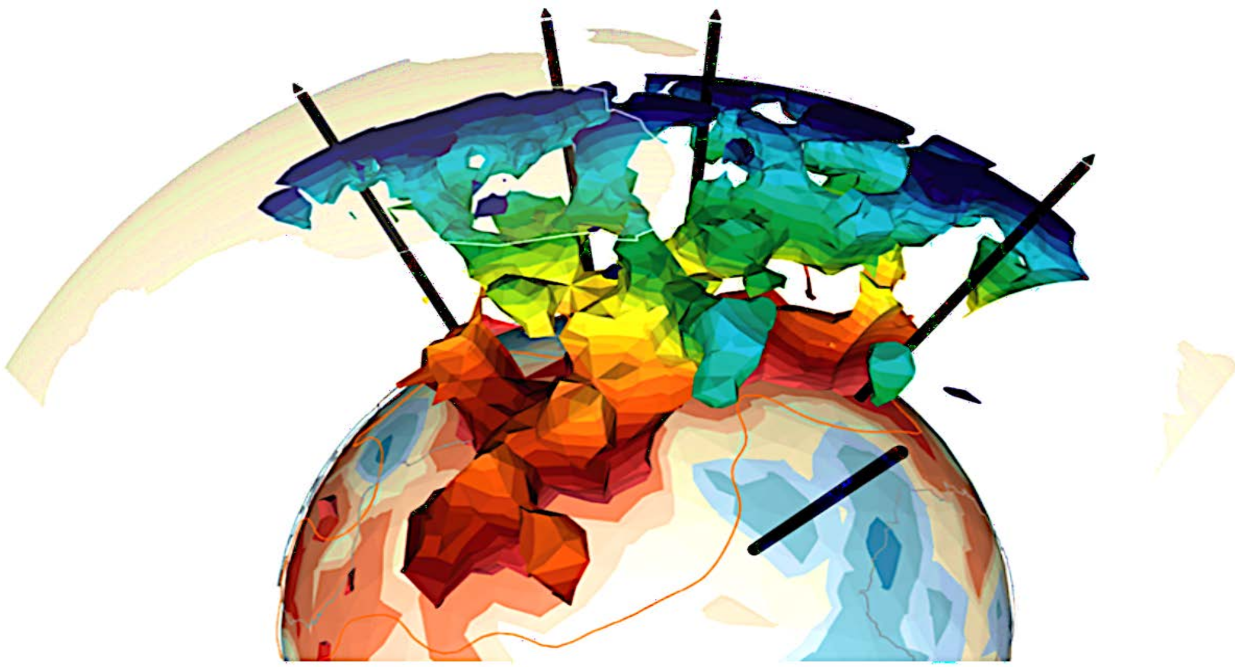
Only half the Earth can face the sun during the flash of the nova, and during impact of the nova shell, so we would expect uneven isotope distribution when such an event is considered.

Surge Deposits: During Einstein's late-life work with Charles Hapgood, his greatest frustration was trying to explain the evidence of continent-sized tsunamis and the turning-over of the earth. Velikovsky, Hibbens, Cuvier, DeLuc and Danjon are among just a few of the scientists over time to see this evidence, as Hapgood and Einstein did, but none ever looked outside an earth-only explanation.

The seismic forcing discussed in Chapter 7 would be greatly amplified in a solar event 100x to 1000x stronger than the ones used to discover the correlations in modern times. This occurs as potential impactors from the event are crashing into the sea. The landslide potential from those earthquakes, especially at marine sites capable of producing tsunamis, would skyrocket. Major volcanic triggering is a legitimate possibility at that level of forcing, especially because much of the high energy cosmic rays of the solar event would be absorbed in the silica-rich mantle, and the electric induction could produce unimaginable activity in the medium. In the images below and on the next page we see why major mantle/core disruptions are an easy way to get major crustal disruptions too.



The blobs, seen from the (a) North and (b) South Poles. The two-toned structures show the shapes of the blob based on the agreement of five different models (brown) and three different models (tan). Credit: Cottaar and Lekic, 2016, https://doi.org/10.1093/gji/ggw324



Seismic tomography imaging shows a portion of a "blob" that sits at the base of the mantle below Africa. Slow-wave velocity regions above the blob, including the cusp and branches, could indicate plumes or upwelling. Credit: Maria Tsekhmistrenko

The mantle blobs would not only serve as easy pathways for the event to induce disruptions in earth's core, but also are subject to disruption themselves, which **could cause tremendous heaving within the mantle**. It becomes easy to imagine "Atlantis sinking into the sea" in this event.

"Explaining all the evidence" was the charge of numerous researchers in this field for three centuries. Numerous researchers, including Einstein and Hibbens, have struggled to explain the great disasters on this planet that seem to come quickly, take many forms, and re-deliver normalcy relatively instantly from a geological timeline perspective. The long history of this investigation often seems strange to those who know it is now not a large part of mainstream discourse on related topics. The absence of this topic from the scientific lexicon has a simple explanation, but many of the details and rationale remain uncertain.

In the great work of Major Maynard E. White's son, Ken White – *World in Peril*, we get full accounts and actual Pentagon documents describing the discovery of this cycle in the Arctic in the late 1940s. It describes the conclusions reached by the Pentagon and Office of Strategic Services (OSS- later would become the CIA) that this cycle occurred approximately every 12,000 years, and it was indeed a magnetic excursion, ice age, and major biosphere extinction event. Major White also reported that they were concerned that the next event was imminent and evidenced by the ongoing magnetic changes on earth.

Interestingly, one of the key individuals at the OSS at that time was Charles Hapgood, who later masqueraded as a professor while still working for the CIA, and during which time he delivered a ridiculous and easily-debunked version of Earth's catastrophe cycle that is commonly known as "crustal displacement". Armed with the foreword written for him by Einstein before he had passed, Earth Crust Displacement Theory surged into popularity for a brief while.

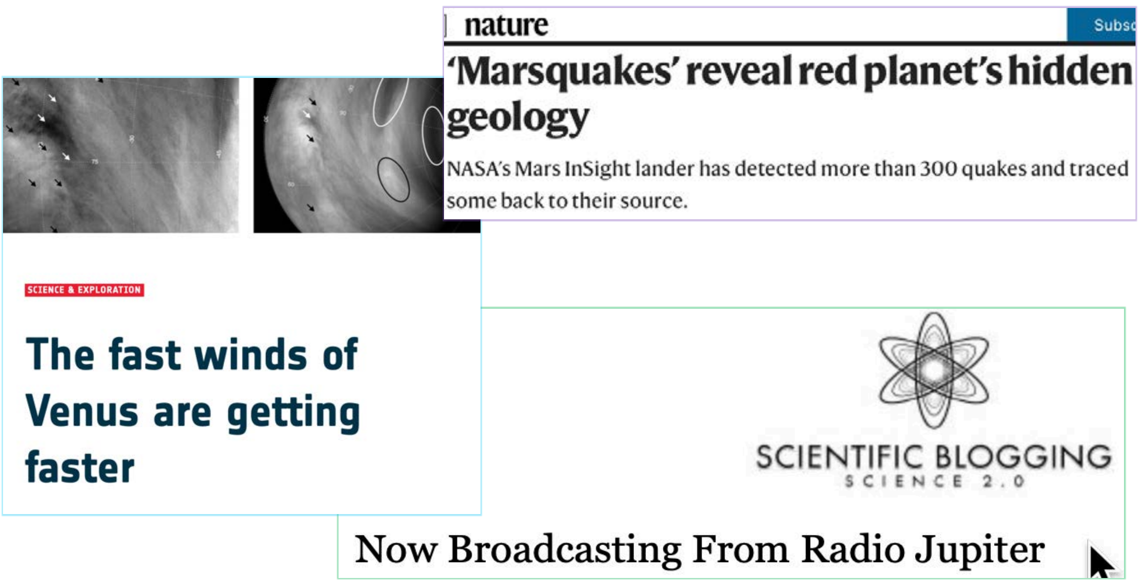
Hapgood’s public (and popularized) version deviates from the classified one of which he was part the decade before- the one reported by Major White. His altered timeline and crustal motion were easily debunked, and were debunked in ways that only apply to his public version- not the one we got from Major White. For example, in the Pentagon version the poles end up back where they began; Hapgood’s did not, and that public version was debunked due to the position of the poles being relatively certain for eons.

What happened between his and the Pentagon’s conclusions in the late 1940s and his nonsense version that got famous in the 1950s and 1960s is anyone’s guess. Whatever the reason, the ridiculousness of the public version is the reason the entire field of catastrophism is seen as “fringe”. With Einstein’s name, Hapgood drew an umbrella over the entire field, and it fell.

From the Toba event to the Gothenburg event there has been a magnetic excursion every 10,000 to 15,000 years; the last one was 12,000 - 13,000 years ago, and the Earth’s magnetic field is changing now like it hasn’t changed in thousands of years. This is a scary set of coincidences.

But aren’t we forgetting something? If this is all unfolding now, and the galactic sheet is acting on the solar system, we should see both (1) magnetic changes on the other planets, and (2) nova or super flare outbursts at the nearby stars in the direction of the galactic center.

Surely, the set of coincidences and explanations for the evidence is interesting, and also happens to comport with ancient human accounts of the solar destroyer. It would be *really* concerning to also have evidence in the rest of the solar system and on other nearby stars… but those are two HUGE orders to fill.



The images above are from just a handful of the articles on the planets and their recent changes.

- Earth is seeing faster winds in tropical storms this decade, but not like Venus, which recently underwent a 33% boost to its fastest winds.

- Mars seismicity is increasing, and scientists say they don't know why. It also has been undergoing temperature shifts larger than the Earth has during the same period.

- Jupiter has seen unprecedented variability in the Great Red Spot and in its colored cloud bands, and recently began emitting a strange radio signal.

- Saturn, Uranus and Neptune have all had superstorm anomalies in their atmospheres, and Uranus has shown increasing auroral activity.

Wind, weather, storms, seismic activity, auroras… these are all things that we have learned are modulated by solar activity, generally can involve the magnetic field of the planet, and if there are recent magnetic changes on those other planets, then we might expect meteorological and crustal activity to change too. Jupiter's radio signals are created by electrons caught in the planet's magnetic field, so if the emissions are changing, either the fundamental character of an electron is changing (not possible) or the magnetic field of Jupiter is changing, and consequently is changing how the electrons are accelerated in the field.

While it cannot be definitively confirmed that these other planets are experiencing anything close to Earth in terms of a planetary magnetic change, this is exactly what we *would* expect to see if that were the case- atmospheric, crustal, and electron acceleration changes. This is as far as human technology can take us at this stage, but in that capacity is a big "check mark" ✓ in the YES column for these changes on the other planets.

That just leaves the nearby stars…

The galactic sheet will be approaching from the galactic center, so we must look to the nearby stars in that line of sight. In the general direction of the center of the galaxy, the Alpha Centauri system and Barnard's Star are the closest. A few year ago the most active member of the Centauri system,

known as Proxima Centauri, had a tremendous outburst 10 to 100 times stronger than its strongest previously known flare. This was considered one of the greater astronomical discoveries of the last decade – the “Proxima Centauri superflare”. Proxima was known to be a flare star, and had been studied well enough that its flare limits had been presumably well-established… and then it had a superflare.

A few years earlier, astronomers noted similarly strange outbursts at Barnard’s Star, which was believed to be an inactive star in terms of flaring before that day. While the outburst was not as powerful as that from Proxima, it represented a much greater change in activity given the quiet nature of the star.

There was also an outburst from the next star in line, Wolf 359, but now we are getting a few decades into light travel and our technology just hasn’t existed at this level for long enough to track much more than this. Our ability to detect these super flares and micronova is relatively new. Even though massive supernovae are recorded over centuries in Chinese and most Western archives, the smaller events are a new opportunity for discovery. Beyond Wolf 359, any out-bursting would have occurred during a period when we may or may not have been able to detect a superflare or micronova event. This is a sad limit of our technology, just like we cannot measure the magnetic changes on other planets.

Still, what you would need to see at the limits of our technology happens to be exactly what we have seen, and up next would be the sun. The cloud of material is already engulfing the solar system, seemingly affecting all the planets. The cycle is repeating now- it is simply a matter of how far into the sheet we are, and how long the sun can resist.

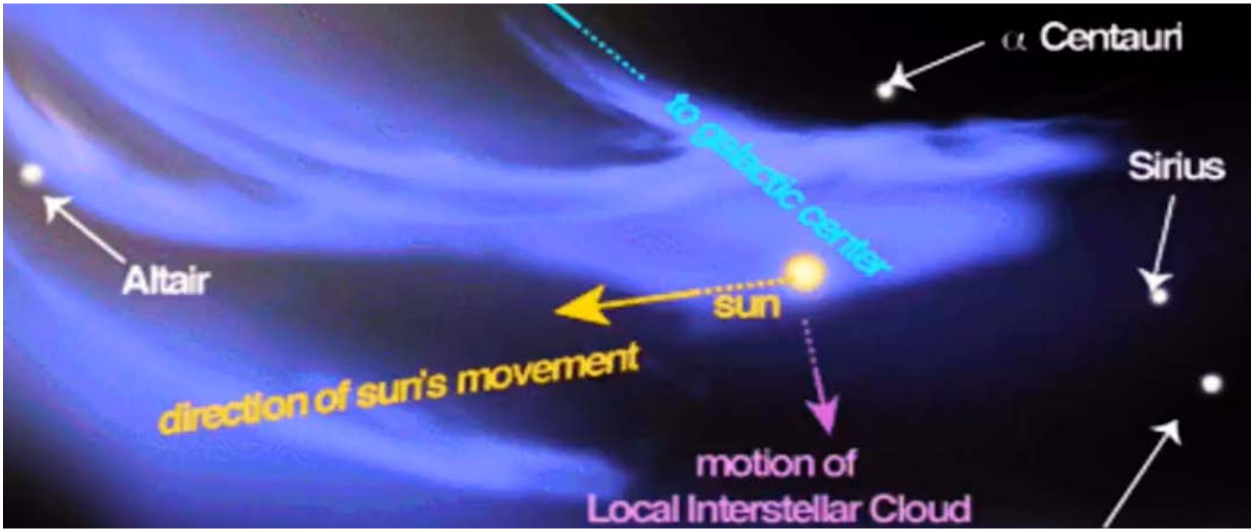
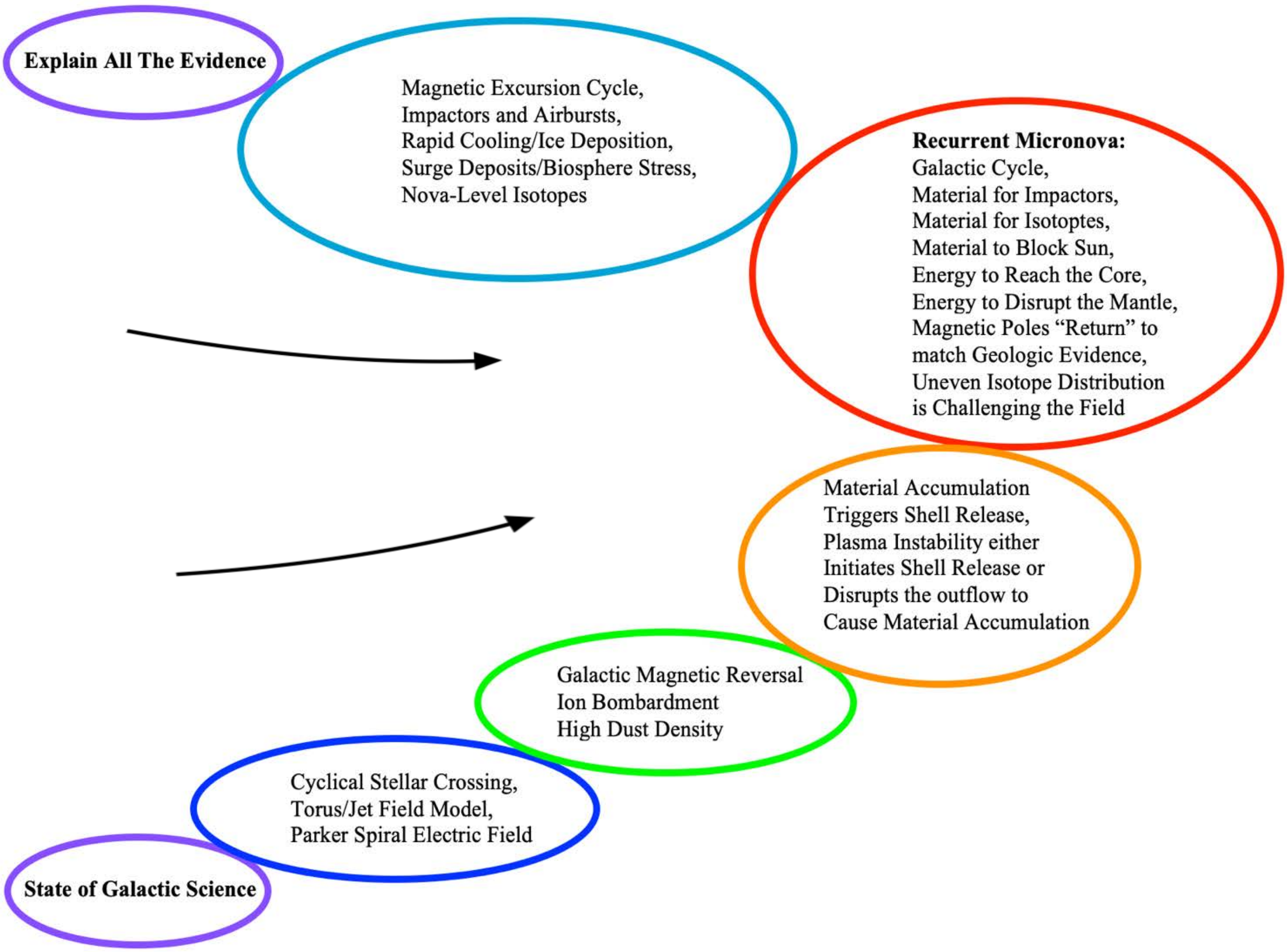


Image from NASA.gov

Whether you begin with the magnetic excursion cycle of earth and seek to explain all the evidence from the isotopes to the climate changes, or with the large scale galactic physics and see what must play out and IS playing out at the nearby stars and throughout the solar system, you arrive at the same place. Our sun is capable of doing something terrible, and it actually becomes difficult to understand how one could avoid this inevitability given the available facts. It IS the only way to currently explain ALL the evidence.

According to Rune Floberghagen, the former head of the ESA/SWARM satellite mission studying Earth's magnetic field, (1) the magnetic pole motion is intimately related to the weakening of the global field, and (2) the last major acceleration of Earth's field loss (~year 2000) took us from losing 5% per century to 5% per decade.

The next major acceleration could put earth within years to a few decades of having a considerably diminished magnetic field. The sun's magnetic field has been fading rapidly (solar polar fields have lost ~40% of their strength in the last half-century, and with another grand solar minimum forecast in the coming decades the sun may be ready to give-in. In almost every cyclical harmonic system the shorter cycle harmonics make up the longer cycles, and the ~400-year grand solar cycle is no exception. This is to say, that when the longer 2400 and 12,000-year cycles reset, it will be during a 400-year cycle reset as well, and unless the magnetic fields of the sun and earth stop the rate of change and rapid accelerations of their shifts, it should not be discounted that this century could mark the end of the long-period cycle. Solar micronova, magnetic excursion, radiation & DNA mutation, impactors, ice age, surge deposits, massive forcing of tectonics, weather and negative health effects – that is a lot to put together. I hope this helps:



Final Comments

The subjects of space weather effects on the weather, technology, seismicity and biology are all relatively new. This text offers a broad exposure to these topics and trends in findings, but it is not a complete picture of the available literature. New papers are coming out in each of these fields almost every month, and given recent trends in funding and researcher interest, that is probably going to continue. As a meteorologist, a space weather enthusiast, an industry professional or a layperson- there is now enough literature and consensus on some topics for you to begin integrating that understanding into your daily life and even your profession.

Better weather forecasting, earthquake prediction, and cosmic energy health alerts are all already here. If these topics directly affect your profession, if you want to learn more on these topics, we invite you to watch our free daily morning news program.

Remember: +140 years of powerful solar flares and geomagnetic events are in the data as decreases in solar forcing. That subtracted amount AND any actual increased-energy effects are attributed to humans.

Our daily Earth/sun updates appear on:

YouTube: Suspicious0bservers
Facebook.com/ObservatoryProject
SpaceWeatherNews.com
Suspicious0bservers.org
ObservatoryProject.com
EarthChanges.org
Instagram.com/MobileObservatoryProject

Real-time Earthquake, Solar Flare, Geomagnetic, and Health Alerts come through

The DISASTER PREDICTION APP
Available for Apple and Android

Acknowledgements:

My wife Katherine is the engine that makes everything run. Without her, there wouldn't be a YouTube channel, let alone books, websites, conferences, an App, etc. She cannot be credited enough for the things we do. She is our CEO, our CFO, she runs our annual Observing the Frontier conference, she writes children's books about science, and helped in the editing process of this book as well.

I would like to thank Todd Cleckner of 9RESE for helping to seek out and organize the research used in this book, and for being an integral part of The Disaster Prediction App, earthquake forecasting, and SpaceWeatherNews.com. He is also one of the leading programmers working on the automation of the earthquake forecasting model into full real-time alert status.

Billy Yelverton runs our plasma lab in Leesburg, Georgia. The earthquake predictions hinged on his ability to turn our imagination into reality in his plasma lab, by recreating the global electric circuit interaction with the crust. You saw many images from his lab in Chapter 7.

The global community of ~500,000 "Suspicious0bservers" fuels our passion, and has driven the successes, education and communication delivered by Space Weather News. They also took a very active part in the creation of this book.

Many 0bservers contributed to making sure we found all the relevant research papers:

Clare Swift, Jason Gamble, Phyllis K. Williams, Elise Gladstone, Joel Gimbel, James Plummer, Jeff Sincell, Kim Murphy, Vincent Cimato, David Woodward, Terrance Allen, John Ingham, John Prescer, Keith Hallam, Brian Spence

Many 0bservers contributed to editing and proofreading the manuscript and reference section:

Joshua Campbell, David Fournier, Nathan Hansen, Kimberly Suwinski, Conrad Ruppert, Jr., Teresa Tidwell, Robert J. Sanchez, Jonathan Hart, Janice M Meris Oliver, Douglas Arthur Rotondi, Jason Sharma, Jim Williams, Ash J. Seidl-Staley, Chad Mires, Kristi Beaupre, Kim Walton, Tony Herrington, William B. Miley, Bonnie Chamberlain, Noah Reutemann, Charlie Harner, Brian P. Slee, Kris Gavin, J K Williams, Christina McPherson, Ian Terrell, Paul Burrell, Jonathan Ingham, John Morgan, Richard Lambertus, Carla Suter, Tom Lawless, Phyllis K. Williams, Diane Valentine, Jeff Venable, Thomas Calvet, Sarah VeganGarden, Robin Coventry, Anthony C. Usera, Desseri Ackerman, L. Altmann, Kenny Nonymous, A.C.E., Börje Öman, Kim Murphy, Buddha Sadu Gains, Jessica Lynn Stalker, Jennifer Jenkins, Andrew Lincicome, Doc Farmer, Kevin Shamel, Michele May, Steven G. Jenks, Burke Steinfelt, Beth Halbrook, Gerardo Herrera, Ryan Dzingle, Jessica Cofrancesco, Cam McNaughton, Wojciech Nowak

Glossary/Acronyms:

Alfvén wave - A wave that occurs in a plasma (or conducting fluid), resulting from the interaction of the magnetic fields within it, causing an oscillation of the ions.

Alpha Sunspot - A sunspot group that contains only one polarity (+ or -); these often have only one sunspot umbra in the group.

AMO - Atlantic Multidecadal Oscillation

Beta Sunspot - A sunspot group that contains both + and - sunspots.

Bow Shock - The area between the magnetosphere and outer space; the bow shock helps force the Solar Wind around the magnetosphere, and is created via solar wind collision with the magnetosphere.

CME - Coronal Mass Ejection

Corona - The solar atmosphere.

Coronagraph - A device that images the outer corona and near-sun space. It is very sensitive, and allows the user to see charged particle ejections, as well as planets and comets, without the glare of the sun washing out the image.

Coronal Hole - An area of the corona with unconnected (open) magnetic fields, which allow solar wind to stream out at a faster rate. Alfvén waves and IMF emanate from the centers of coronal holes.

Coronal Mass Ejection - An erupting cloud of plasma and charged particles from the sun that goes out into space; CMEs can be produced from solar flares or filament eruption/collapse.

Cosmic Rays (Galactic Cosmic Rays 'GCR') - High-energy radiation that mainly originates from outside the solar system. Galactic cosmic rays are atomic nuclei stripped of electrons.

Delta Sunspot - A sunspot group where both a + and - sunspot umbra co-exist in close proximity within a penumbral area; this requires both polarities, a Beta Class sunspot, and is the most likely class to produce solar flares.

Ejecta - The particles of a CME; the material that leaves the sun during a solar flare or filament release.

EM - Electromagnetic

ENSO (El Niño Southern Oscillation) - The oscillation between El Niño and La Niña.

Filament (Plasma Filament, Solar Prominence) - A tight line of plasma and charged particles suspended above the solar surface by the sun's magnetism.

Flux Transfer Event (FTE) - The flood of charged particles that streams into Earth's electromagnetic system every 8 minutes via magnetic portals (IMF) in near-Earth space.

Forbush Decrease - A rapid decrease in the measurable GCR count during a coronal mass ejection impact, which is brought on by charged particles and magnetic fields contained within the CME, acting to block GCR.

Galactic Cosmic Rays (GCR) - High-energy radiation that mainly originates from outside the solar system. Galactic cosmic rays are atomic nuclei stripped of electrons.

Gamma Sunspot - A sunspot group where + and - sunspots are spread out and dispersed such that they cannot be grouped together by a continuous line; this requires both polarities, or a Beta Class sunspot.

Gamma-Ray Burst (GRB) - A highly luminous flash of light that produces gamma rays, which are the most energetic form of electromagnetic radiation. Satellites measure the initial flash and then the longer-lived afterglow that is emitted at longer wavelengths. GRBs are thought to be a source of galactic cosmic rays and were first discovered by accident in the 1960s as a result of the Limited Nuclear Test Ban Treaty.

GCR - Galactic Cosmic Rays

GEC - Global Electric Circuit

Geomagnetic Storm - The disruption to Earth's magnetosphere due to space weather.

Geomagnetically Induced Currents (GIC) - Produced by the naturally induced geoelectric fields that occur during geomagnetic disturbances (storms); GICs can impact electric power-transmission systems and other electrically-conducting infrastructure as they are manifestations of space weather at the ground level. GICs are modulated by impulsive geomagnetic disturbances, which are created by the interaction between the Earth's magnetosphere and the sharp velocity, density and magnetic field enhancements in the Solar Wind.

Global Electric Circuit - A flow of electricity connecting through the ground, atmosphere and ionosphere.

(Solar) Grand Cycle - The ~400-year cycle of higher-activity solar cycles and lower-activity solar cycles.

(Solar) Grand Maximum - The highest activity period (multiple sunspot cycles) of a grand cycle; lots of sunspots/solar flares/geomagnetic activity.

(Solar) Grand Minimum - The lowest activity period (multiple sunspot cycles) of a grand cycle; fewer sunspots/solar activity.

Halo Eruption - A CME on SOHO LASCO that appears to be coming out of all sides of the central disk that blocks solar glare and is indicative of an Earth-directed CME. (NOTE: A CME on the exact opposite side of the sun from Earth may produce a Halo as well, so we need to confirm that the Solar Flare or Filament Eruption is on the Earth-facing side of the sun before it is declared that an eruption is heading our way.)

Heliosphere - The magnetic shield of the sun, extending out past all the planets; the sun’s version of a magnetosphere, encompassing the entire solar system.

Heliospheric Current Sheet - The boundary between northern and southern IMF in the solar wind, where the sheet defines the boundary between outflowing magnetic fields and those streaming back to the sun.

IMF - Interplanetary Magnetic Field

Induction (Induced) - The process by which electric currents and magnetic fields initiate electric current flow in resonantly synced/tuned material. Example: Electrojets above our heads induce electric currents in the ground.

Interplanetary Magnetic Field (IMF) - The magnetic fields connecting the planets to the sun.

Interplanetary Shockwave - The sudden boundary that is formed at the front of a coronal mass ejection, which is moving faster than the rest of the solar wind. These shocks interact with the Earth's magnetosphere, often causing geomagnetic storms.

Magnetic Portals - The vortex-shaped IMF connection that forms where Earth’s magnetic field pushes against the sun’s magnetic field, allowing charged particles to stream into Earth’s systems in an FTE.

Magnetopause - An abrupt boundary between a magnetosphere and the surrounding plasma; it is the thin space separating shocked solar wind plasma from the plasma contained within the magnetosheath.

Magnetosheath - The region of space between the magnetopause and the bow shock of a planet's magnetosphere.

Magnetosphere (Earth’s magnetic shield/field) - A magnetic shell that surrounds the Earth and protects the planet from space energy.

NAM - Northern Annular Mode

NAO - North Atlantic Oscillation

OLR (Outgoing Longwave Radiation) - Thermal heat escape from the Earth.

Penumbra - The area surrounding dark sunspot cores, appearing as lines surrounding the sunspot, pointing back toward the center of the sunspot.

PDO - Pacific Decadal Oscillation

Polar Vortex - A wintertime stratospheric vortex over the polar region. Strong vortices hold cold air at the pole, weak vortices are referred in the news as “Polar Vortex Events”; they bring major winter cold events as it spreads out and loosens its grip on the polar air.

QBO - (Quasi-Biennial Oscillation) - An upper-atmospheric flow from east to west and vice-versa, oscillating back and forth every few years.

Radiation Storm (Solar Radiation Storm, Solar Energetic Particle Event) - A surge of charged particles that bombard the upper atmosphere at Earth's polar regions; usually caused by a strong solar flare.

SAM - Southern Annular Mode

SEP - Solar Energetic Particles (almost always protons, often called 'solar energetic protons')

SOHO – The Solar and Heliospheric Observatory, a solar-watching satellite that was made partially obsolete by the Solar Dynamics Observatory (SDO), although the coronagraph images remain highly useful for space weather prediction in CME tracking.

Solar Energetic Particles - High-energy protons and electrons that accelerate to velocities much faster than the ambient solar wind. They are produced by strong solar flares and travel to Earth via the IMF.

Solar Flare - A burst of X-ray energy released when umbral magnetic fields interact, surging charged particles and plasma in the corona to near the speed of light.

Solar Polar Fields - The sun's high-latitude IMF, which drive the sunspot cycle, and may trigger massive earthquakes when peaking in strength or reversing polarity.

Solar Pole/Magnetic Reversal - The flip or reversal of the sun's magnetic poles; the north and south poles reverse polarity (+ and -) every ~11 years.

Solar Prominence - See "Filament".

Solar Sector Boundary Crossing (SSBC) - The change in solar wind magnetism as the heliospheric current sheet undulates to take Earth across the solar wind equator.

Solar Wind - The constant flow of charged particles and neutral elements away from the sun in every direction; the solar wind blows out to distances past Pluto.

Space Weather - Forces that act upon Earth, which are external to the Earth; solar events, comets, meteors, galactic cosmic rays, etc.

SPF - Solar Polar Fields

Sunspot - A highly magnetic region of the sun where magnetic fields emerge from inside the sun.

Sunspot Classification - The characterization of sunspots in terms of likelihood to create solar flares based on the magnetic structure of a sunspot or group of sunspots.

Sunspot Cycle - The ~11-year cycle of increased/decreased sunspot activity on the sun.

Sunspot Maximum - The period of the sunspot cycle with more sunspots/solar flares/geomagnetic activity.

Sunspot Minimum - The period of the sunspot cycle with fewer sunspots/solar flares/geomagnetic activity.

TEC (Total Electron Content)- Density of electrons in a segment of the atmosphere.

Total Solar Irradiance - Solar heating of the upper atmosphere, varies 0.1% over the sunspot cycle

TSI total Solar Irradiance

UHF – Ultra-High Frequency

ULF – Ultra-Low Frequency

Umbra - the dark inner core of the sunspot.

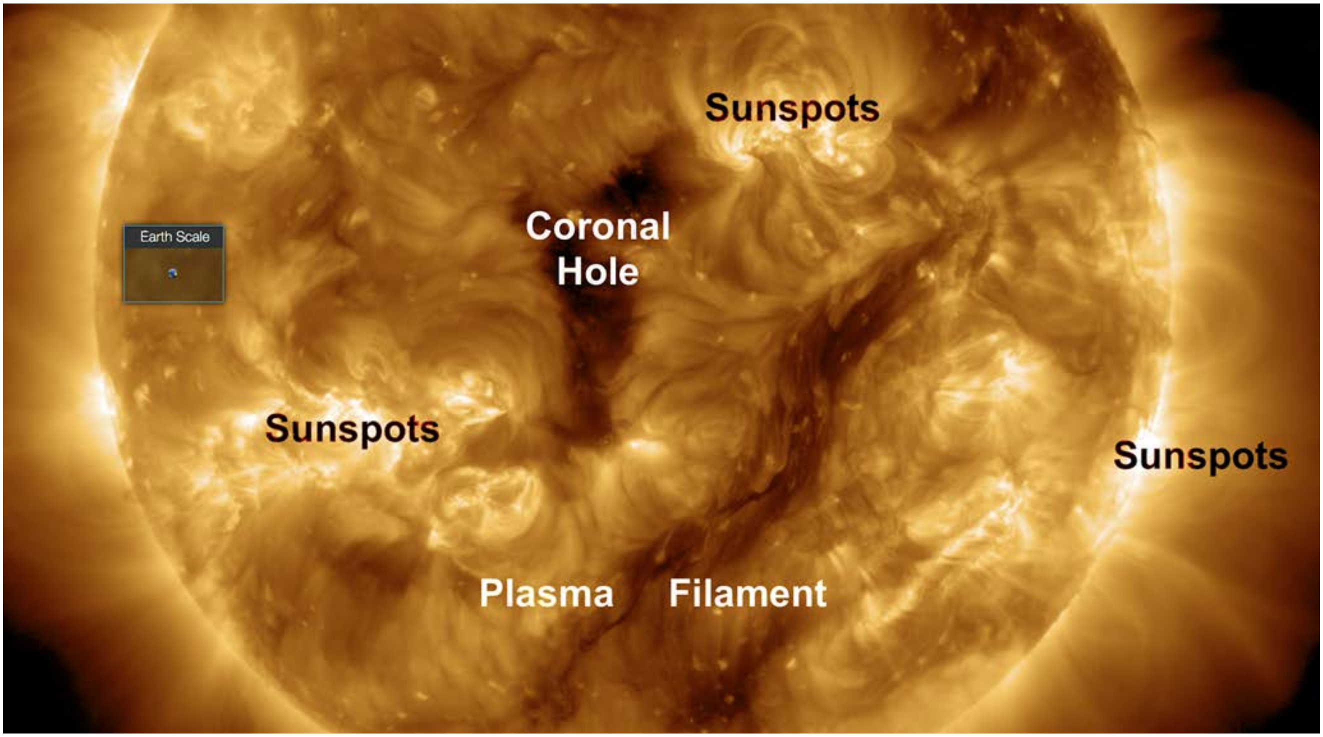
Umbral Magnetic Field (Umbral Field) - The magnetic fields (loops) that connect sunspots to each other, or to magnetic surface areas around the spots.

UV - Ultraviolet light; a form of photon wave energy.

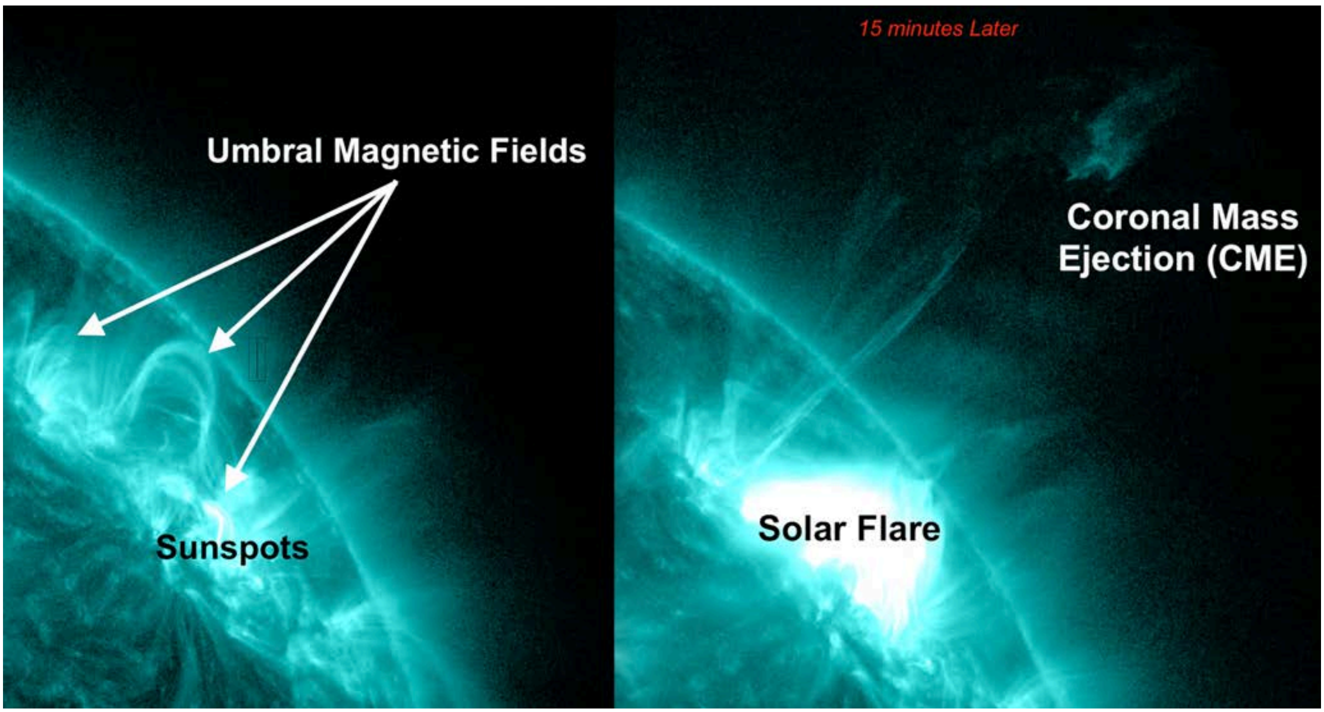
VHF – Very High Frequency

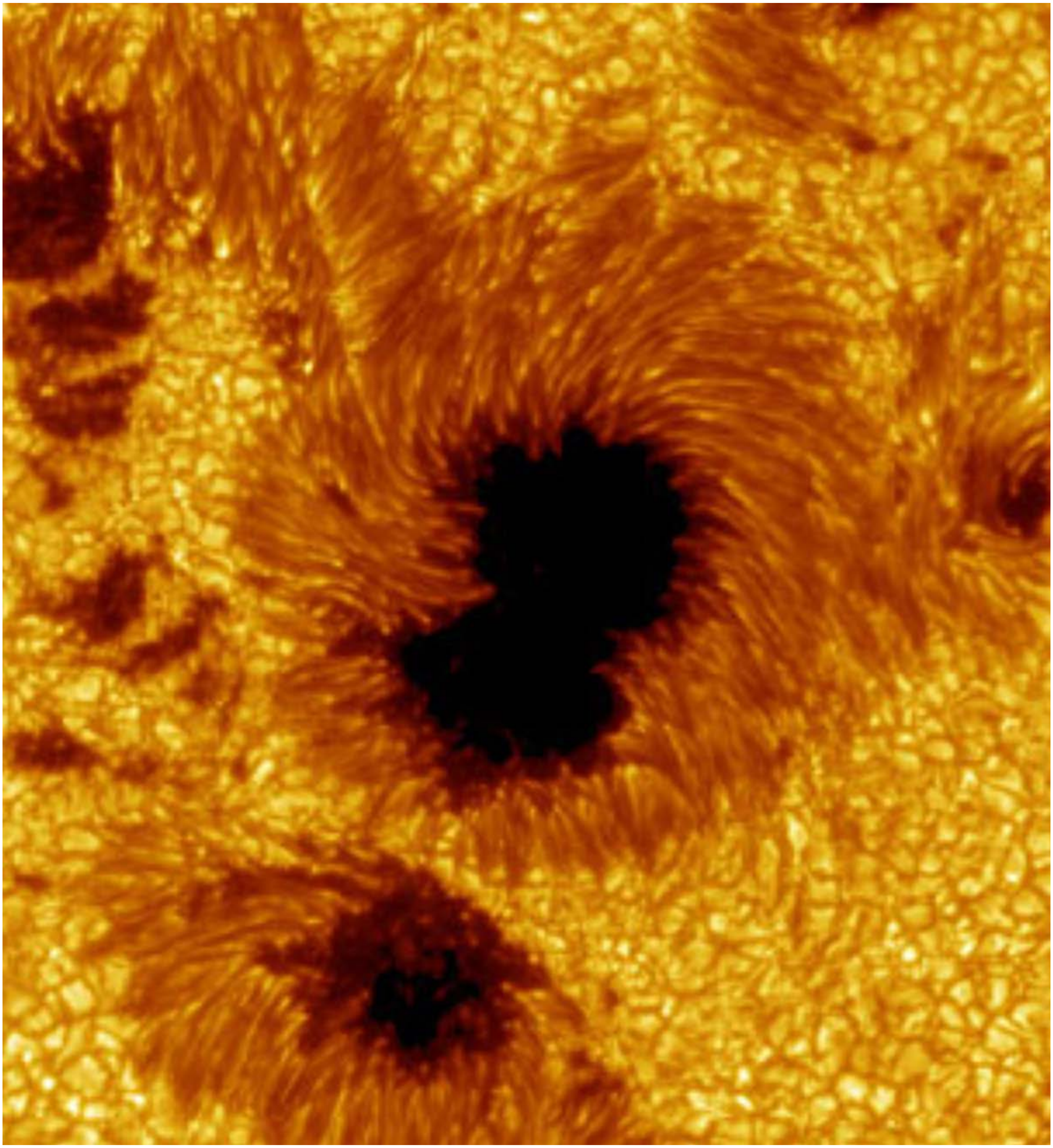
UHF – Very Low Frequency

Infographics:



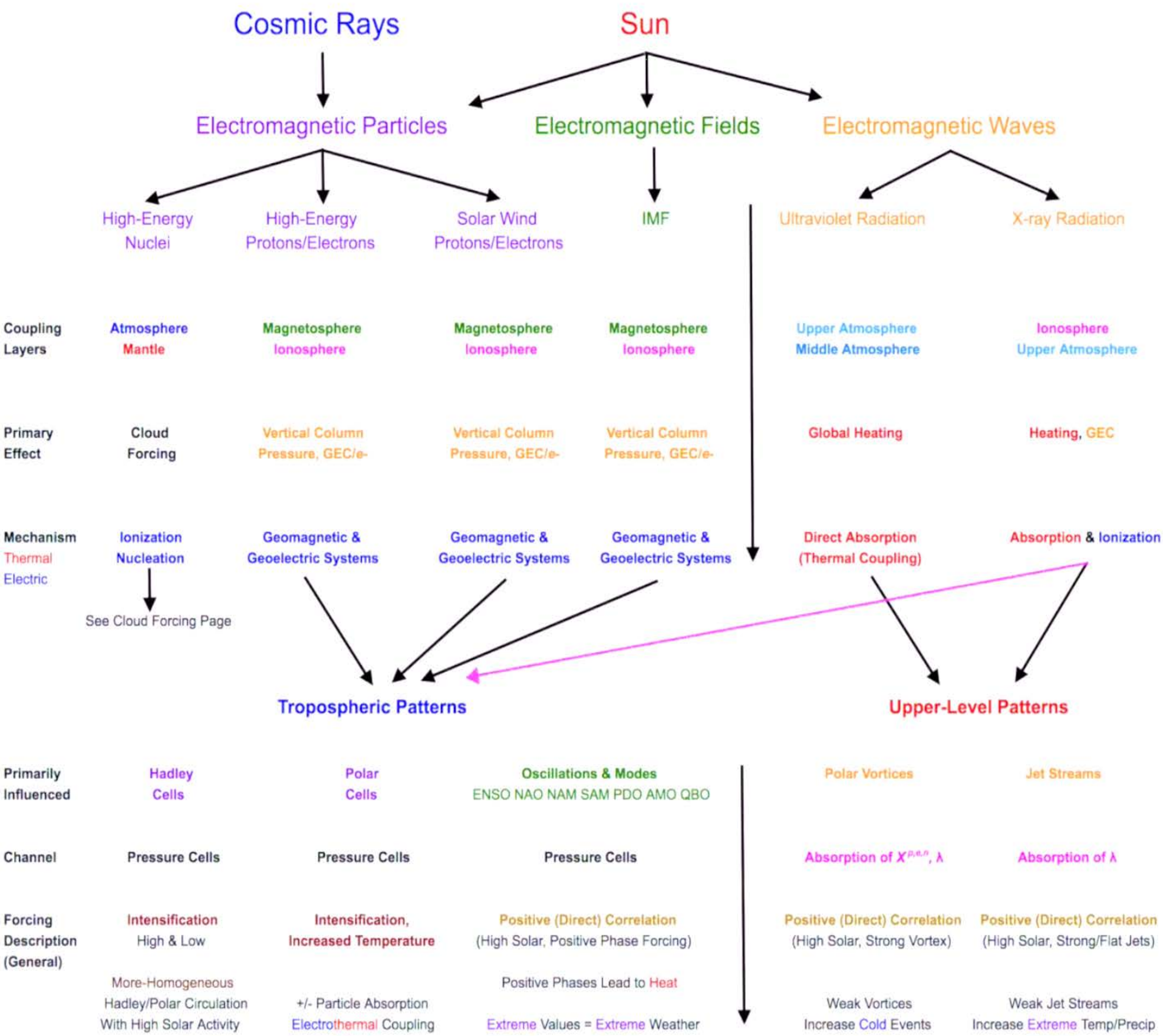
Top: SDO/AIA 193 Ångströms *Bottom:* SDO/AIA 131 Ångströms





Sunspots: The dark cores (sunspot umbra) are where the magnetic fields/currents come in and out of the sun. The interaction of those fields/currents is what causes solar flares. The orange hair-like filaments surrounding the umbra are the sunspot penumbra, and are an electric effect caused by the fields/currents. The yellow cellular areas are the visible surface, and each cell is called a granule.

SPACE WEATHER CLIMATE FORCING



SPACE WEATHER CLOUD FORCING

	Galactic Cosmic Rays	**Solar Energetic Protons**	**Earth's Electrons**
Source:	Galaxy/Beyond	The Sun	Van Allen Belts
Modulation:	11yr Solar Cycle	Solar Flares/CMEs	CME Impact
Cause:	Energetic Space Events	Energetic Solar Events	Magnetosphere Compression
Penetration:	Atmosphere/Mantle	Atmosphere	Atmosphere

	Air Ionization	**Particle Nucleation**
How?	Ambient Particle Electrification (Makes Them More Attractive to Dust/Water)	Direct Particle Deposition (Electric Charge Attracts Dust/Water)

Oscillation and Mode Forcing

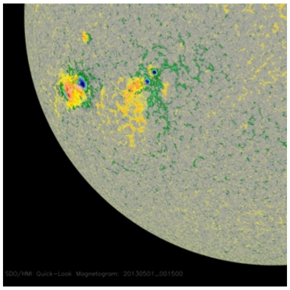
Climate Pattern	ENSO NAO PDO AMO NAM SAM	QBO
Forcing from High/Low Solar	Positive/Negative Phase	Decreased/Increased Effects
Primary Effect	LOCAL-SPECIFIC! Generally, positive phases mean warmer earth. The more extreme the phase value, positive or negative, the more extreme the weather.	Individual Effects on Oscillations/Modes
Proposed Mechanism(s)	Solar driven changes in Pressure (Vertical Column), Hadley Cells, and Upper Jets **UV Heating [Thermal Coupling]**	Phase-Dependent Solar Forcing Boost/Reduce

What can we learn from the key studies in this section?

1) **Solar Flares can trigger an immediate and lasting (days to weeks) of positive forcing.**
2) **Strongest forcing lag is 1-4 years from sunspots, indicating geomagnetic conditions are concurrent.**

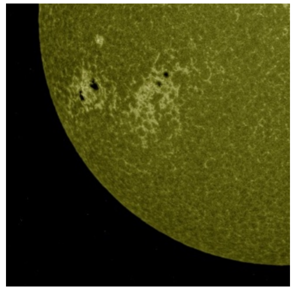
GUIDE TO THE SOLAR DYNAMICS OBSERVATORY (SDO) SATELLITE

ALL IMAGES FROM MAY 1, 2013

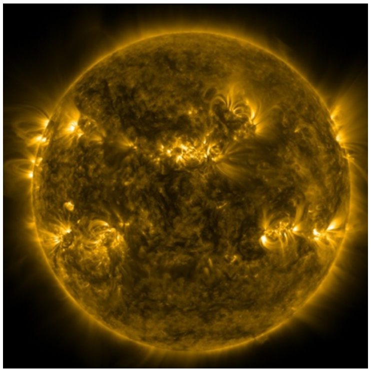


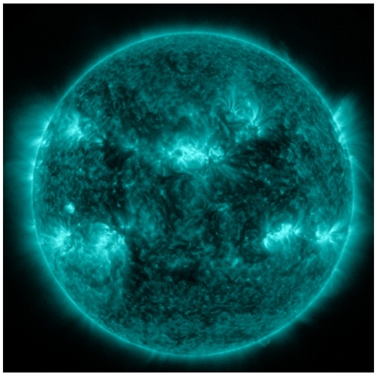
Left: Neutral Iron Magnetogram. It shows the sunspots and their magnetism (red/blue).

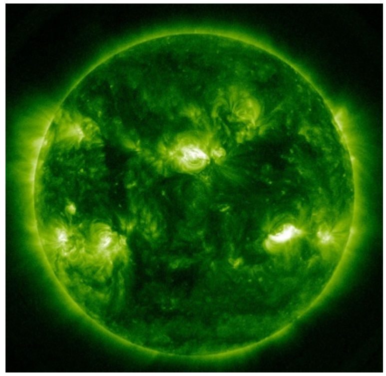
Right: Ionized Carbon. The sunspots (black) and magnetic field connectivity is visible in the lighter yellow areas around the sunspots, and which also have polarity shown on the left.

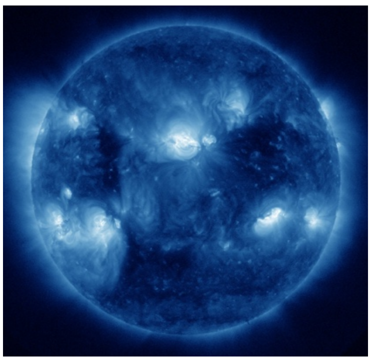


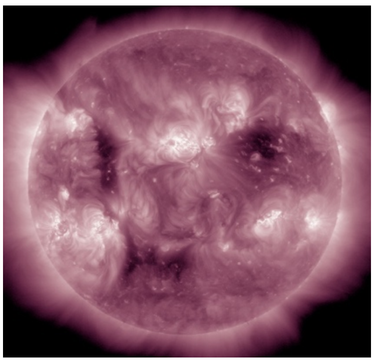
THE IRON GROUP: ALL SHOWING VARIOUS IONIZATIONS OF IRON (Fe)

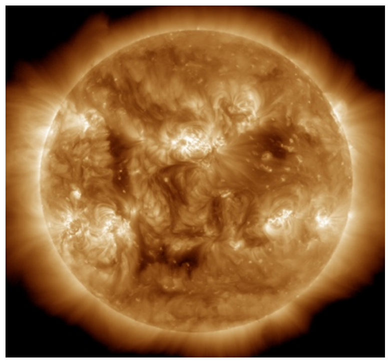








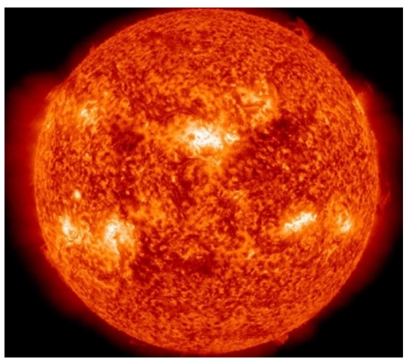




Top Left to Bottom Right: AIA Wavelengths 171, 131, 94, 335, 211, 193. Lower wavelengths in the top row show bright sunspot areas and umbral magnetic fields in great detail. Higher wavelengths in the bottom row show the boundaries of coronal holes.

THE 304A VIEW OF IONIZED HELIUM

The magnificent red-colored Helium view of the sun reveals sunspots, a hint of the coronal holes, and shows the best-of-all structure of plasma filaments. It also shows CMEs in extreme detail due to the high Helium content of CME outbursts.



FINAL EXAM

Space Weather

1) The sun emits electromagnetic wave energy (photons) in: (Circle one)

   a) X-rays and Radio Waves
   b) All energy ranges
   c) Microwaves, Visible, Ultraviolet
   d) UV, Visible, Infrared, Gamma Rays

2) The solar wind contains _____________.

   a) Heavy/large molecules
   b) Small electrically charged particles

3) In which direction does the solar wind flow?

   a) Outward from the Sun in All Directions
   b) North to South
   c) Inward Towards the Sun due to Gravity

4) Does the solar wind make it out to Jupiter? _____ Neptune? _____ Pluto? _____

   Write Yes or No in the blanks.

5) Which of these is the most abundant particle in the solar wind?

   a) Protons
   b) Helium
   c) Water
   d) Oxygen

6) How many different elements have been detected in the solar wind?

   a) 2
   b) 7
   c) 23
   d) Nearly all of them

7) Fill in the blank: The density, _________, and temperature of the solar wind particles are the most important/most basic data points we measure.

8) The undulating region between north and south hemispheres of the solar wind is called the heliospheric ___________ _________. (Two words)

9) The interplanetary magnetic fields: (Circle all that apply)

a) Connect to the sun at sunspots.
b) Connect to the sun at coronal holes.
c) Connect the planets to the sun.
d) Exchange electromagnetic wave energy between Earth and sun.
e) Exchange electromagnetic particles between Earth and sun.

10) What do we call the atmosphere of the sun?

a) Corona
b) Sunspot
c) Photosphere
d) Iris

11) The magnetic imager uses the visible spectrum, and can see sunspots; what neutral element is seen by this imager?

a) Iron
b) Hydrogen
c) Carbon
d) Helium

12) Fill in the blanks: The dark center of the sunspot is the ________________ and the area surrounding the center is called the ________________.

13) The umbral magnetic fields [loops] at sunspots contain: **charged / neutral** particles.

14) How long is the sunspot cycle (in Earth years)?

a) ~1 year
b) ~2 years
c) ~7 years
d) ~11 years
e) ~25 years

15) The magnetic fields associated with sunspots often interact, collide and entangle, which can cause:

a) A sunquake
b) A solar flare
c) Sunlight production
d) Sunspots growth
e) Sunspot decay

16) Fill in the blanks: A solar flare can excite the atmosphere and cause a communications disruption known as a _______ blackout.

17) List the classes of solar flares, from lowest energy to highest energy (5 of them):

____

18) Which generally comes first, the solar flare or the CME? ________________

19) What can cause CMEs besides a solar flare? _________________

20) Describe the difference in solar wind telemetry between a CME impact and a coronal hole stream

21) What is the name of the sun's magnetic shield?

a) Magnetosphere
b) Heliosphere
c) Magnetoshield
d) Solarsphere

22) Where are Earth's three auroral electrojets found?

23) What level indicates a more severe Solar Energetic Particle Event: (Circle one)

S2 or S4

24) What is the space-weather event that comes to Earth and causes a Geomagnetic Storm

a) Sunspot
b) Solar Flare
c) CME (Coronal Mass Ejection)

25) What are the two most important characteristics of a CME for guessing its strength? (Circle Two)

a) Speed
b) Color
c) Density
d) Brightness

26) Do the magnetic field at coronal holes loop back down or reach out into the solar system?
____

27) Do coronal holes produce faster or slower solar wind? _______________

28) Which solar wind telemetry rises first during coronal hole impact at Earth, density or speed?
____

29) Can coronal holes cause geomagnetic storms? ________________

30) Sunspot Magnetic Classifications:

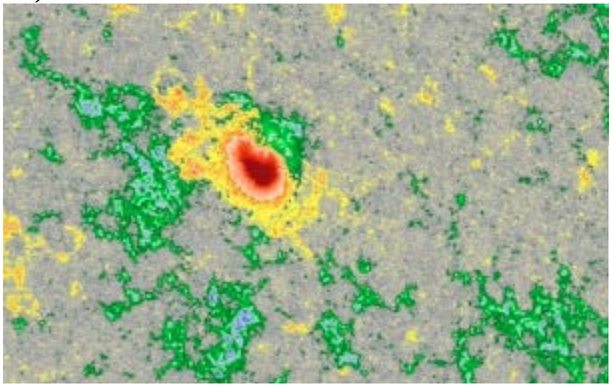
a) Alpha	___ Where both + and - sunspots are found in a group of sunspots
b) Beta	___ Where + and - sunspots cannot be separated by a continuous line
c) Beta-Gamma	___ + and - sunspots close together within one penumbral region
d) Delta	___ Only one polarity (+ or -) can be found in the sunspot group

31) Which of these sunspot classifications is not possible to see? And why?

a) Beta-Delta
b) Alpha-Gamma
c) Beta-Gamma-Delta
Why?

Sunspot Classification Exercise: To the right of each of the following images, write the sunspot class, and give a reason for your answer. Remember not to confuse surface magnetism around a sunspot with an actual sunspot region - only the umbral magnetism is a factor in sunspot classification.
[Blue - Positive, Red - Negative]

32)



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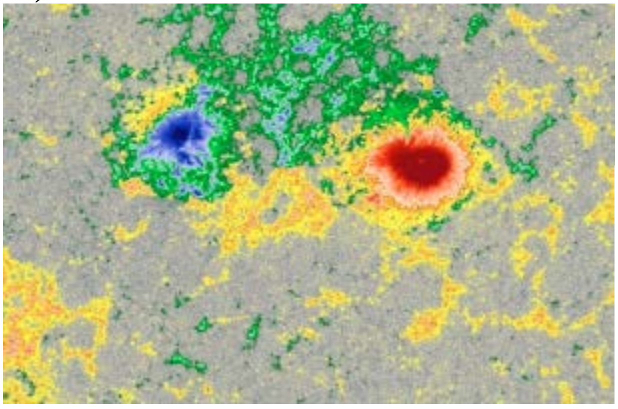

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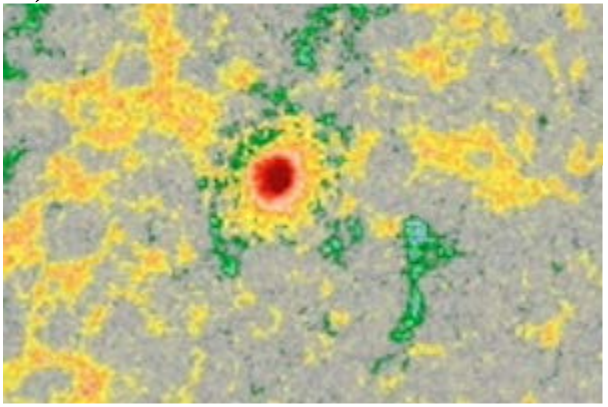

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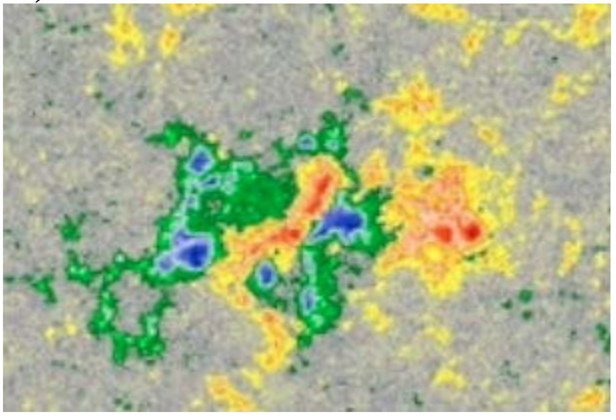

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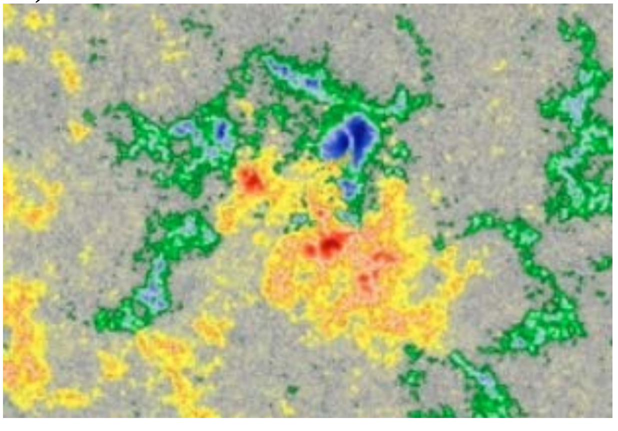

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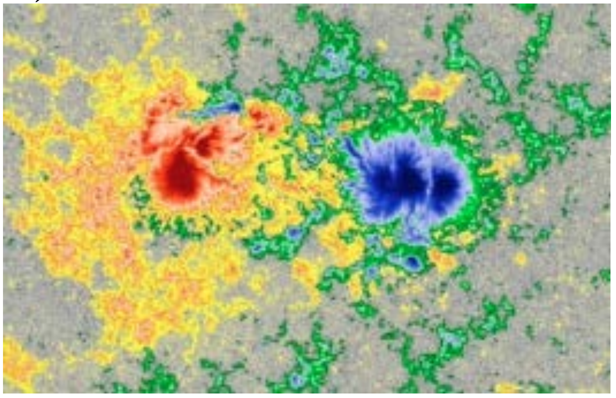

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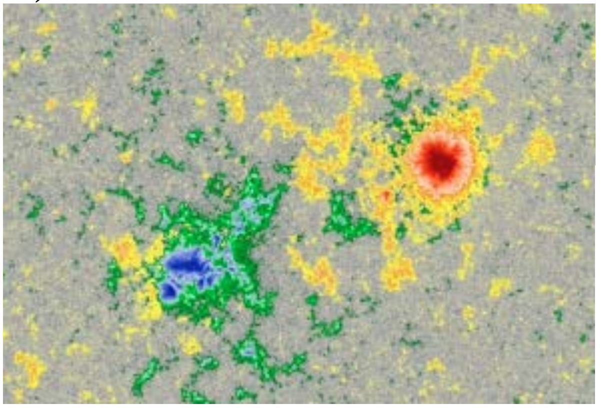

____

____

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____

____

39) Which period is the closest to the rotation speed of the sun?

a) 1 Earth day
b) 27 Earth days
c) 2 Earth months
d) 1 Earth year

40) How long is the sunspot cycle? ______________

41) Geomagnetic storm maximum/minimum are at the _____________ as the sunspot maximum/minimum.

a) same time (direct relationship)
b) opposite time (indirect relationship)

42) The Solar Polar Magnetic Fields are at maximum/minimum are at the ____________ as the sunspot maximum/minimum.

a) same time (direct relationship)
b) opposite time (indirect relationship)

43) Galactic Cosmic Rays (GCR) maximum/minimum are at the ____________ as the sunspot maximum/minimum.

a) same time (direct relationship)
b) opposite time (indirect relationship)

44) How often do the sun's magnetic poles reverse? ______________________

45) Approximately how long is the grand solar cycle? ______________________

46) Which SDO/AIA wavelength view is best for seeing coronal holes?

a) 171 Ångströms
b) 211 Ångströms
c) 304 Ångströms

Climate Forcing

1) List 4 Significant Climate Oscillations/Modes and the effect of solar maximum/high solar activity on each of their phases.

2) Which phase of solar activity is more likely to produce weaker upper atmospheric jets, jet stream blocking, and polar vortex weakening? (Circle one)

a) Solar Maximum
b) Solar Minimum

3) Solar __________ produces more severe winter cold events in the northern hemisphere. (Maximum or Minimum?)

4) Solar forcing of large-scale oscillations and pressure cells is likely to be driven by its modulation of: (Circle all that apply)

a) UV heating received by the upper atmosphere
b) Upper atmospheric jets
c) Ocean currents/temperatures
d) Hadley cells
e) Centers of pressure cells
f) Auroral electrojets

5) Space weather modulation of large-scale oscillations is likely the indirect driver of space weather correlations with temperature and precipitation, with the exception of__________________________________: (Circle one)

a) the equator, where the change in TSI drives the correlations directly.
b) the poles, due to the lessened factor of sunlight, where direct particle effects have a larger effect.

6) Space weather has access to the entire atmosphere via its interaction with the ionosphere, and the (circle one):

a) Stratosphere
b) ENSO Cycle
c) Global Electric Circuit

7) What type of space weather modulates cloud cover and lightning? (Circle all that apply)

a) Solar flare x-rays
b) Solar energetic particles
c) Galactic cosmic rays
d) Auroral ions
e) Electrons from the magnetosphere
f) Electrons from the Van Allen belts
g) Electrons from the moon

8) In the global electric circuit, the current goes down/up in ______/______ pressure.

9) Tropical Storms Essay: Describe the effect of solar activity on tropical storms, some of the thermal/electric coupling aspects of solar forcing that would be affecting the storms, and the manner in which the correlation appears to be changing.

10) Long-Term Forecasting Essay: Presuming it is an especially long-lasting and low-activity sunspot minimum phase, describe the expected effects (and why) on winter temperature in Europe, central Pacific sea surface temperatures, and the cloud cover across the Earth. Include any lagged-time for the modulation to take effect.

11) Short-Term Forecasting Essay: Presuming a tremendous solar flare erupts, the SEP stream limit is reached, and a halo CME is visible on SOHO -describe the relevant space weather and Earth weather impacts expected in the following days in terms of high altitude safety and meteorological phenomena.

12) Describe what happens to total solar irradiance measurements during large solar events, and two other ways that those events directly affect other layers of Earth.

13) Asian monsoon failures tend to occur more-often during grand solar ____________ (Maximum or Minimum?)

14) During which phase does the USA Southwest get less rain, while the eastern/central states have fewer droughts?

a) Grand Solar Minimum
b) Grand Solar Maximum

15) Whereas "solar forcing" has traditionally been limited to thermal coupling due to upper-atmospheric heating, numerous short-term pathways of modulation appear to exist via ___________ coupling. (Circle One)

a) Thermal
b) Kinetic
c) Dynamic
d) Electromagnetic
e) Mechanical

16) What are the two ways the galactic cosmic rays, solar energetic protons and magnetospheric electrons can affect cloud cover and lightning?

17) Global electric circuit current comes down from ionosphere under _____ pressure.

a) High
b) Low

Technology & Human Health

1) Humans and technology are more vulnerable to space weather during: (Circle all that apply)

a) High Solar Flaring
b) Low Solar Flaring
c) High Solar Energetic Particle Flux
d) Low Solar Energetic Particle Flux
e) High Geomagnetic Activity
f) Low Geomagnetic Activity

2) Magnetic field resonance can affect the locus coeruleus, and our ability to handle stress and panic. These resonances occur: (Circle One)

a) During the solar flare
b) During the geomagnetic storm

3) Major solar storms like the Carrington and Charlemagne event, which would put the entire electrical grid at risk, occur how often?

a) 11 years / 100 years
b) 100 years / 200 years
c) 100-200 years / 1000 years

4) When was the Carrington event? ________ The Charlemagne event? _______

5) ______________ directly affect cognition and memory through changes in the hippocampal tissues. (Fill in the blank)

6) What is considered the Kp index "safe zone" for biological life?

a) 7-9
b) 6-9
c) 3-7
d) 4-5
e) 2-4

7) Comprehension/Communication Essay: Describe the changes in space weather-disruption of technology in 2015 and in the time since then. Describe how they relate to the changes in tropical storm forcing during the same time from both a temporal and causative perspective.

8) Which of the following may be affected during a geomagnetic storm? (Circle all the apply)

a) GPS
b) Internet
c) Cellular Networks
d) Home Appliances
e) Power Grids

9) Strong ____________ have been shown to be positively correlated with convulsive seizure events. (Circle Two)

a) Solar Flares
b) Geomagnetic Storms
c) IMF Reversals

10) List three of the mental/psychiatric effects of strong solar flares or geomagnetic storms:

11) Which part of the brain is known to be affects by cosmic rays?

a) Medulla Oblongata
b) Cerebrum
c) Hippocampus

Earthquakes

1) Magnitude 6+ Earthquake fluctuations above/below the 3/week long-term average is related to: (Circle One)

a) Solar flaring activity
b) Geomagnetic storm activity
c) Coronal hole IMF

2) Magnitude 8+ Earthquakes tend to occur: (Circle one)

a) During X class solar flares
b) During peaks and polarity reversals of the solar polar magnetic fields
c) During solar wind impact from coronal holes

3) Which of these describes an aspect of a Blot Echo earthquake foreshock in the successful seismic forecasting model?

a) Deep Earthquakes
b) Shallow Earthquakes
c) Surface Ruptures
d) Low Pressure Atmosphere

4) Short Comprehension Essay: Describe "Earthspots" in the context of pressure, current flow, and expected weather.

5) Which of these super-lithospheric signals present themselves before numerous large earthquakes? (Circle all that apply)

a) Blot Echoes
b) TEC anomalies
c) GPS disruptions
d) Magnetic field ultra-low frequency (ULF) resonance
e) Magnetic field very low frequency (VLF) resonance
f) Magnetic field ultra-high frequency (UHF) resonance
g) Magnetic field very high frequency (VHF) resonance
h) Outgoing Longwave Radiation anomalies
i) Atmospheric pressure anomalies
j) Jet stream blocking

6) Short Comprehension Essay: For forecasting earthquakes, why are Earthspots used to track electromagnetic anomalies instead of all of the other factors?

Extreme Solar Activity

1) Major solar storm activity in 1859 and 2003 is thought to have briefly raised temperatures:

a) Tens of degrees
b) A Few Degrees
c) A Few Hundredths of a Degree

2) Astronomers believe that if the sun has periodic super flare activity, it happens approximately every:

a) 25,000 – 30,000 Years
b) 12,000 – 15,000 Years
c) 1000 – 2400 Years
d) 200 – 400 Years

3) Have any other sun-like stars been known to have super flares?

a) Yes
b) No

4) What is a micronova, and what is one type of nova that is smaller than a micronova?

5) Which fission track isotopes found in the bones of surge deposits indicate our sun has had a nova event during these tremendous catastrophes?

a) $Carbon^{14}$ and $Oxygen^{13}$
b) $Xenon^{24}$ and $Krypton^{81}$
c) $Aluminum^{26}$ and Transuranic Elements

6) What aspect of a nova event at the sun causes a rapid cooling?

7) Name two previous magnetic excursions:

8) How often has Earth endured a magnetic excursion over the last ~72,000 years?

9) How long ago was the last one?

10) Describe observed changes on two other planets that may indicate a magnetic change ongoing at those planets:

11) What feature in the solar system is most like the galactic current sheet? How is the galactic version different?

12) What two potential nova-triggers are delivered to a star as it crosses a galactic current sheet?

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ANSWER KEYS:

Space Weather

1) b
2) b
3) a
4) Yes, Yes, Yes
5) a
6) d
7) speed
8) current sheet
9) b, c, e
10) a
11) a
12) umbra, penumbra
13) charged
14) d
15) b
16) radio
17) A, B, C, M, X
18) solar flare
19) plasma filament eruption
20) CME impact shows as simultaneous increases in intensity, while coronal holes have a leading density shockwave, followed by faster/hotter solar wind.
21) b
22) poles and equator, high and low latitude
23) S4
24) c
25) a, c
26) reach out
27) faster
28) density
29) yes
30) b, c, d, a
31) b, gamma class requires beta class
32) Alpha Class - We have one spot, red negative. The blue positive areas surrounding it are surface magnetism.
33) Beta Class - Negative on the right, positive on the left.
34) Alpha Class – There is one negative spot.
35) Beta-Gamma-Delta Class - We have positive and negative spots, the positive spots are split around the central negative zone, and the positive spot furthest to the right is within the same penumbra as the negative spot to its left.
36) Beta Class - Positive and negative spots. Do not let the odd shape and number of spots fool you into thinking it is something more complex.
37) Beta-Gamma-Delta Class - We have positive and negative spots; the positive spot at the top left is separated (gamma) and within the same penumbra as the negative spots below (delta)
38) Beta Class - Positive and negative spots.
39) b
40) ~11 years, 9-13 years
41) a
42) b
43) b
44) every 11 years
45) 400-440 years
46) b

Climate Forcing

1) Positive forcing: ENSO, PDO, AMO, NAO, NAM, SAM. QBO: Phase cycle modulation.
2) b
3) minimum
4) b, d, e
5) b
6) c
7) b, c, e, f
8) high/low
9) Answer based on section 5.3; using the GEC/particle energy on top of large-scale oscillation modulation; correlation appears to be strengthening as the magnetosphere weakens, allowing space weather to have more-direct access to the atmosphere/GEC.
10) Lower winter temperatures over Europe on ~1-3 years lag due to negative phase forcing of the NAO, and the weakening of jet streams and polar vortex; decrease in temperature on ~1-3 years lag due to shifting of location/strength of Pacific pressure cells related to ENSO, and the stronger Brewer-Dobson effect taking low latitude heat to higher latitudes; increased cloud cover immediately due to increased cosmic rays.
11) An expected 2nd punch of SEP is expected in a few days when CME impact occurs. Geomagnetic storms are expected. Astronauts and polar airline flights may need to take precautions. Refer to Sections 4.1 - 5.5 for weather effects- the question is broad/open, and the answers may vary greatly, but recall we're looking only for a short-term forecasting essay on the timescale of a few days.
12) TSI goes down during large solar events, incorrectly indicating a drop in solar energy received. X-ray solar flares disrupt the ionosphere, CME impact disrupts the magnetosphere.
13) minimum
14) b
15) d
16) Aerosol cloud nucleation, ionization of existing particles
17) a

Technology & Human Health

1) a, c, e, f
2) b
3) c
4) 1859 AD, 775 AD
5) Galactic cosmic rays, SEP, magnetospheric electrons
6) e
7) Answer describes the **increase** in number of technological disruptions **during** space weather events, the **same ones** as when weather records occurred. Looking for something on the magnetic field weakening recently, allowing for easier space weather access to the atmosphere/technology, and it is helpful to describe how CO_2 changes and other anthropogenic factors are unlikely to account for both.
8) All
9) b
10) cognitive diminution, anxiety, depression, emotional instability, degraded memory, higher suicide risk
11) c

Earthquakes

1) c
2) b
3) a
4) Current goes down in highs, up in lows. Lows bring more storms, while highs tend to have more fair-weather sunny days.
5) b, c, d, e, h, i
6) Earthspots are where the GEC is strongest, the other data points are very hard/impossible to track and rapidly analyze for forecasting purposes, monitoring the GEC is almost like monitoring them all at once anyway.

Extreme Solar Activity

1) b
2) c
3) a
4) Micronova is a smaller version of a supernova or classical nova. It is disastrous but does not destroy the planets or the star. Best answers: Dwarf nova, type 1 x-ray burst)
5) c
6) The dust of the nova blocks the sun, both in the inner solar system, and in the upper atmosphere (like a volcanic or nuclear winter).
7) Gothenburg, Mono Lake, Lake Mungo, Laschamp, Vostok, Toba
8) 10,000 – 15,000 years
9) 12,000 – 13,000 years ago
10) Venus – faster winds driven by magnetic changes allowing more space weather forcing. Mars – increased seismic activity due to changing magnetic fields. Jupiter – many weather changes, changes in electron radio emission from magnetic field. Saturn, Uranus, Neptune all show weather and/or auroral anomalies.
11) Solar wind (heliospheric) current sheet. The solar system sheet is more pristine, whereas the galactic sheet carries more gas and dust from nova events.
12) Electromagnetic Plasma Instability (from the galactic magnetic reversal and ion component) and Classical Coronal Explosion (due to extra material dumped into the atmosphere of the star).

About Space Weather News:

Space Weather News began as a simple YouTube channel in 2011. Videos initially focused on reporting newsworthy solar events, weather events and earthquakes. It quickly became clear that the same things on the sun and earth were being reported together over and over again.

The investigation of these patterns revealed not only a solid relationship between the sun and the earth, but also the struggle of those publishing in these fields to gain recognition of the science.

In 2014, we launched on a USA/Canada tour to meet scientists, students and citizens. After 41 States and 4 Canadian provinces we had met 1000s of people, made connections between researchers in the field, and left a wake of young minds fascinated with the sun over the 25,000-mile journey.

Since that time, we have launched an app that tracks space weather and seismic activity, released two children's books introducing the sun and solar system to more young minds, and created an annual conference that host scientists and professors delivering fascinating information about these topics first-hand.

The progress of solar climate forcing has become a major movement in science. As stated near the beginning, it is not hard to fall in love with watching the sun via our best satellites, and it is continually fueled by the real-world relevance of these events, which can dwarf the excitement of the greatest works of fiction ever told- and all of it is real.

Space Weather News, our YouTube channel Suspicious0bservers, our websites and our conferences have become like a family reunion that happens all the time. There is something deeply human about watching the natural world to learn more about your personal one, and with solar particle forcing about the enter the "official" climate models for the first time, I do not think we have even seen the start of the tsunami.

Space Weather News is a family company. We have three young children and they are often crawling over us as we work on various aspects of the organization. We work with various 3rd parties and volunteers, but at the end of the day this all is "home" for us.

Katherine H. Davidson, CEO, SpaceWeatherNews

Thank you for taking the time to read Weatherman’s Guide to the Sun. This book is a compilation of daily observations and years of diligent research, and it was a titanic effort to pull-together a variety of scientific disciplines. We are a family company, and our viewers come from all walks of life and locations around the globe. Your acknowledgement as an 0bserver is well deserved.

Sincerely,

Ben Davidson, CS0, SpaceWeatherNews
‘S0’